Water Quality and Circular WASH in Focus: Greywater Monitoring in Transitional Housing Communities in Eugene

by

Edith Sackitey

A thesis accepted and approved in partial fulfillment of the

requirements for the degree of

Master of Science

in Environmental Studies

Thesis Committee:

Kory Russel, Chair

Matthew Polizzotto, Member

University of Oregon

Summer 2025

THESIS ABSTRACT

Edith Sackitey

Master of Science in Environmental Studies

Title: Water Quality and Circular WASH in Focus: Greywater Monitoring in Transitional Housing Communities in Eugene

There has been a need to push for sustainable solutions to water management. Water management strategies like greywater recycling can serve as a tool to tackle the increased demand on water resources due to increasing populations, etc, assist water-stressed and deprived regions in conserving and managing their limited water resources, homeless communities, and other communities post-disaster in establishing a reliable water reuse system. Homeless communities and communities post-disaster often do not have access to safe water and sanitation services. Several regions in the world are water-stressed, such as the Middle East (UAE and Jordan), the Netherlands, Turkey (Istanbul), Oman, and the United States (California, Arizona, Texas, etc). Water scarcity can have cascading effects. It is detrimental to the growth of the economy, heavily decreases the availability of food, and greatly puts pressure on the environment. Greywater systems result in less extraction of water from streams and rivers and minimize the quantity of wastewater that passes through sewer or septic systems. The presence of *Escherichia coli* was tested using IDEXX Colilert. *E. coli* is a widely accepted indicator of the presence of human fecal bacteria contamination and, as such, is correlated to disease risk. The goal of the systems is to improve environmental and social outcomes, thus enhancing the quality of life of communities by cutting costs and providing a strong and safe water management strategy. Greywater recycling has demonstrated promise as a sustainable and feasible alternative water management approach for the future, most importantly, those regions that are laden with water scarcity.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Improved water management strategies are likely essential given forecasts of severe water scarcity in many parts of the world (Vuppaladadiyam et al., 2019). One possible alternative for recycling greywater is a decentralized strategy that distinguishes the wastewater streams of a household with acceptable sanitation (Vuppaladadiyam et al., 2019). There has been increasing demand for water resources globally stemming from increased populations, urbanization, and industrialization (Larsen et al., 2016). Only 0.5% of water on Earth is readily accessible and usable as freshwater. This has been attributed to climate change (WMO, 2021). Climate change and the associated stochasticity of weather events will further strain water resources (WMO, 2021). It is estimated that by 2050, 4.8–5.7 billion people could exist in regions characterized by a likelihood of water scarcity for at least a month each year (Wallin et al., 2021). Against this backdrop of uncertainty, novel strategies to ensure the sustainable management of current and future water reserves are emerging (Bolton & Randall, 2019). Water management strategies such as greywater recycling, a decentralized strategy that separates wastewater streams based on levels of contamination, could serve as a tool to help tackle the increased pressure on water resources.

Increasing the scope and frequency of greywater use could help improve the accessibility of water and protect scarce water resources (Kordana-Obuch et al., 2023). Water scarcity is detrimental to economic growth, agricultural production and can put intense pressure on the environment and biodiversity (Boufaroua et al., 2013). Thus, there is a need to push for the deployment of sustainable water management processes and technologies (Garrick et al., 2020). Pushing for sustainable solutions to water management is both socially and ecologically urgent. As water and wastewater infrastructure ages, there are increases in non-revenue water as well as increased public health crises and severe outbreaks of infectious diseases. These issues, in turn, are prompting cities globally to rethink, renovate, and redesign their various water and wastewater treatment systems (Kobayashi et al., 2020).

Greywater Recycling and Sustainability

There has been a rise in interest in the separation and reuse of distinct wastewater fractions, such as grey, storm, and blackwater, mostly owing to structural, economic/financial, and environmental factors (Ottoson & Stenström, 2003). Bolton and Randall (2019) further postulate the heightened interest in exploiting the reuse potential of greywater resources globally due to the relatively high volume and low contamination levels, which require less treatment. Recycling greywater implies that less water is extracted from streams and rivers, and a reduced quantity of wastewater passes through sewer or septic systems. Greywater research has been conducted in water-scarce areas such as the Middle East (UAE and Jordan), the Netherlands, Turkey (Istanbul), Oman, and the United States (California, Arizona, Texas, etc) (Paleologos et al., 2019). Greywater recycling can be very beneficial for purposes or activities that do not demand or necessitate potable water quality. According to Kordana-Obuch et al. (2023), making good use of greywater is a consequential step towards both Sustainable Development Goal Six (Clean Water and Sanitation) and Sustainable Development Goal Seven (Affordable and Clean Energy). Additionally, greywater and its multiple treatment systems could play a significant role in supporting/assisting countries, especially developing countries, to address the Sustainable Development Goals (SDGs) Goal 6, clean water and sanitation for all (Siwila & Kapesa, 2022). Objective 6.3 which relates to ensuring a 50 percent cut in the sum of untreated greywater and substantially enhancing global recycling and safe reuse

(Siwila & Kapesa, 2022). Traditionally, the construction of extra water infrastructure, such as dams, has been employed to tackle urban water scarcity and enhance water supply. However, large infrastructure projects are resource-intensive and limit options for municipalities in the event of threats to the water supply, as was seen in Cape Town, South Africa, in 2019. In contrast, decentralized greywater reuse can diversify and increase the volume of water resources at a lower cost since non-potable activities do not require the highest quality water (Leong et al., 2017). A simple example can be found in the US, where roughly ~57% of wastewater from an average home could be classified as greywater (DeOreo et al., 2016). Additionally, the average US home uses ~50% of total tap water consumption for irrigation (DeOreo et al., 2016). Thus, by capturing greywater and using it for irrigation, you are reducing the amount of tap water, which in this example would be a reduction in tap water consumption of ~25%.

Houselessness

While there are numerous ways researchers could and have begun studying methods for greywater reuse, currently, transitional housing communities for houseless individuals are a pressing social issue that desperately needs improved water resources. Houselessness in the United States is increasing at an alarming rate, driven in large part by low housing stocks and rapidly rising housing costs. Lane County, Oregon, is currently dealing with a housing affordability crisis. Eugene, Oregon, the largest municipality within Lane County, is characterized by some of the highest rates of homelessness per capita in the United States (Bonkoski, 2023). In 2015, 1 in 217 individuals experienced homelessness at some point in the United States. Of that number, African Americans constituted 41.4% of the sheltered houseless population (Solari et al., 2016). A total of 1.48 million individuals were homeless at a point in 2015, all year round (Solari et al., 2016). This indicates that homelessness was an issue even before the COVID-19 pandemic. Based on the 2025 Point in Time Count (PIT) conducted the night of January 29, 2025, there were 3,509 individuals facing homelessness in Lane County. This represents a 24 percent increase from 2023 and a 14 percent increase from 2024, where 2824 and 3085 individuals were considered homeless. Out of the 3,509, 96 of them were residing in transitional housing (Lane County Human Services Division, 2025).

To find solutions for the housing crisis in the Pacific Northwest, Community Supported Shelters (CSS) has created and deployed an innovative temporary transitional housing community model. CSS is a non-profit that builds and operates Safe Spot Communities, which are intended to be cost-effective intentional communities that provide unhoused individuals with essential needs: shelter, safety, food, water, restrooms, and human connection. They are designed to be a transitory step on the way to more permanent housing, for stays from 3 months to 2 years. The CSS housing first model has been successful at placing residents in permanent housing as compared to other placements in a standard shelter system. The CSS village model is one that leverages unused land in urban settings to build off-grid, non-permanent communities for the unhoused. This means CSS must truck in potable water and remove greywater at multiple locations every week. According to CSS, the average cost to truck greywater to the wastewater treatment facility is on average ~$4,000 per site per year. Additionally, the need to truck water in and out means the ability to offer showering facilities, clothes washing, or create garden spaces at the sites is limited or impossible.

Greywater planters have been installed at five CSS safe spot communities to reduce the amount of greywater needing removal. These planter systems evapo-transpirate the water using wetland plants meaning there is little or no greywater to be removed leading to a significant reduction in costs. This planter system adheres to type 1 greywater reuse under the Oregon Department of Environmental Quality (OR DEQ) regulations (Figure 1). However, a greywater system that allows CSS to safely reuse greywater for gardens would not only save considerable labor but also enhance the quality of life for its clients. Moreover, CSS Safe Spot communities currently use porta-potties for on-site sanitation, and limited quantities of water are only for cooking and drinking. Greywater recycling and monitoring could lead to improved environmental and social outcomes, thus enhancing the quality of life of communities by cutting costs and providing a strong and safe water management strategy. However, in order to reuse greywater for watering plants and sanitation services, the greywater would need to be type 2 or 3 greywater under the Oregon Department of Environmental Quality (OR DEQ) regulations (Figure 1).

Oregon's rules recognize three different "types" of graywater, based on graywater quality. Higher-quality graywater can be used in more ways than lower-quality graywater.

- **Type 1 graywater** is graywater that is untreated or has passed through a physical process to remove solids, fats, oils and grease. Type 1 graywater is the lowest quality and may be used only for subsurface irrigation.
- **Type 2 graywater** is treated by a chemical or biological process to reduce total suspended solids and organic matter concentrations. Because this type of graywater is stabilized through treatment, it may be used for drip irrigation and in landscape ponds.
- **Type 3 graywater** is treated to Type 2 standards and disinfected to reduce bacteria and other potential pathogens. Because of its high level of treatment, Type 3 graywater is suitable for additional uses, such as sprinkler irrigation and dust control.

Figure 1: Oregon DEQ graywater types from the OR DEQ Rules on Graywater Reuse and Disposal Systems: Fact Sheet (https://www.oregon.gov/deq/filterpermitsdocs/graywaterrules.pdf)

This research focuses on the effectiveness of the current greywater planters to meet type 2 or 3 greywater reuses standards if no additional treatment technologies were added. Thus, water testing will be conducted to determine the effectiveness of the systems to reduce biological contamination and allow reuse. This will involve sampling of greywater to test for the presence of fecal indicator bacteria such as total coliforms and *E. coli* to ascertain the quality of the treated wastewater. The testing in this thesis is not meant to provide statistically significant results. Instead, it is meant to qualitatively survey the constructed planters to answer several research questions which will allow the CSS to move forward with the next stages of their greywater reuses project with a greater understanding of what is needed.

The researcher seeks to answer the following research questions:

1) Is there total coliform and *E. coli* contamination of the initial greywater before it enters the greywater planters?

2) Is there total coliform and *E. coli* contamination of the greywater after it has passed through one greywater planter?

3) Did initial tests of Biosand filter reduce contamination of total coliform and *E. coli* contamination?

4) Is the current greywater planter system sufficiently treating the water to type 2 reuse standards?

CHAPTER II

REVIEW OF LITERATURE

Greywater Sources, Characteristics, and Potential

There is a paradigm shift in the water sector where wastewater is not regarded as waste but as a resource in the process of recovering and recycling. This can be seen in the renaming of wastewater treatment facilities to Water Resource Recovery Facilities (WRRF) (Coats & Wilson, 2017). Greywater contributes to approximately 50 – 80 percent of wastewater emanating from residential buildings and households (Quispe et al., 2022). What makes greywater a great option for water recycling is relatively low levels of fecal contamination, making it suitable for separate collection and treatment at the household level (Ajit, 2016). Aside from greywater's potential to influence water savings, greywater reuse can aid in the minimization of the eutrophication potential (EUP), human health carcinogenic potential (HHCP), and global warming potential (GWP) in the process of providing water services to the community (Kobayashi et al., 2020).

Greywater recycling can reduce the quantity of freshwater needed by households and decrease the amount of wastewater delivered into sewer or septic systems (Pachkor et al., 2017). According to Sudarsan and Renganathan (2011), it has been demonstrated that recycling treated grey water for toilet flushing is a more effective way to minimize the use of drinking water and a better approach for conserving water than rainwater harvesting/collection. Oteng-Peprah et al. (2018) also argue that recycling greywater is a more reliable approach to ensuring a sustainable water supply for non-potable activities compared to other means like rainwater harvesting, which must rely on the regularity of precipitation in each area. Greywater reuse is thus claimed to be a sustainable way of reclaiming wastewater to meet the demands of a growing population (Quispe et al., 2022).

Greywater reuse and treatment is a good water management strategy to tackle pressing wastewater disposal and water supply challenges that come with industrial and population growth (Pachkor et al., 2017). Greywater generation from households is approximately 50 – 80 percent of household wastewater (Van de Walle et al., 2023). Greywater, which is termed as household wastewater that does not constitute toilet water, usually comprises wastewater from kitchen sinks, washing machines, dishwashers, showers, bathtubs, and hand basins (Pidou et al., 2008). Greywater can be generated from sources such as sinks, washing machines, and showers or bathtubs. However, on a broader scale, all sources are utilized to optimize water savings, whereas on a smaller scale, extremely contaminated sources like kitchen sinks, dishwashers, and washing machines are typically excluded (Pidou et al., 2008).

Kitchen sinks sources are classified as either grey or blackwater depending on different jurisdictions. A large amount of greywater generated from households is deemed as low-load greywater from wash basins and showers and possesses low or no fecal contamination (Siwila & Kapesa, 2022). Testing greywater for chemical, biological, and physical properties is a good strategy that can give an idea of purification pathways suitable for specific reuse (Pachkor et al., 2017). Substances like oil, soap, food particles, microorganisms, dirt, and salt are considered typical greywater contaminants. The chemical makeup and concentration of contaminants in greywater are usually thought to be highly variable since greywater emanates from different wastewater sources (Bolton & Randall, 2019).

Greywater Composition

The composition of greywater can differ depending on climatic conditions, lifestyle, and plumbing fixtures. Additionally, employment and generation rates of greywater differ significantly from one location to the other, and each reuse application has a distinct quality criterion or standard (Oteng-Peprah et al., 2018). Furthermore, wastewater generation is always connected to the resident population's water-use habits, making it less susceptible to water stress situations (Levine & Asano, 2004). Greywater composition varies depending on lifestyle choices and the chemicals used for cleaning, bathing, and washing. The type of distribution network, as well as the quality of the water supply, can influence greywater qualities. Greywater composition alters dramatically over time and space, possibly due to variations in water use relative to outflow/discharge volume. Chemical and biological breakdowns of some substances/compounds across the storage and transit network may further influence the composition (Oteng-Peprah et al., 2018). Oteng-Peprah et al. (2018) highlight that the amount of greywater generated in a household can range substantially from as little as 15 L per person per day in disadvantaged/impoverished communities to hundreds of L per person per day. Additionally, geographical location, habits, culture, climatic conditions, infrastructure type, and lifestyle are among the factors that lead to such wide disparities.

Notable constituents of grey water encompass total suspended solids (TSS), fecal coliform (FC), chemical oxygen demand (COD) biochemical oxygen demand (BOD), oil and grease, ammonium (NH4 +), boron (B), total phosphorus (TP), and surfactants (Friedler, 2004; Travis et al., 2008). Wastewater from kitchen sinks/dishwashers and dishwashing machines are not an ideal source of greywater as it may contain certain impurities or contaminants such as organic matter, oil and grease, and surfactant, which makes treating the water difficult and may impact the efficiency of the treatment method used. Despite the tendency of greywater to contain hair, food particles, grease, and other forms of contamination, it is still appropriate to use greywater, especially for non-potable uses (Pachkor et al., 2017).

Greywater Characteristics

Biological characteristics

Some microorganisms identified in greywater include helminths, bacteria, and protozoa. These microorganisms are usually brought in via physical or bodily contact. Enteric pathogenic bacteria such as Salmonella and Campylobacter have been reported to enter greywater via inappropriate handling of food in the kitchen, including direct handling of food that has been contaminated (Ottoson & Stenström, 2003; Maimon et al., 2014). Fecal contamination is not atypical and prevalent in greywater. Fecal contamination mostly occurs due to the disposal of greywater characterized by laundered nappies/diapers and poor personal hygiene.

For instance, a microbiological monitoring study in Melbourne, Australia, discovered enteric viruses and pathogenic Escherichia coli in greywater. These enteric viruses and pathogenic Escherichia coli in greywater were linked to much of the water coming from laundry sources (O'Toole et al., 2012). In this investigation, 11% of the samples tested positive for E. coli, 7% had enterovirus, and 18% had enteric viruses (O'Toole et al., 2012). Coliform bacteria and E. coli are the most utilized indicators of fecal contamination (Oteng-Peprah et al., 2018).

Physical Characteristics

Components such as, but not limited to, electrical conductivity, temperature, suspended particles, and turbidity, are linked to the physical characteristics of greywater and therefore are some factors that affect greywater's physical properties. A temperature range of typically between 18 to 35 degrees Celsius is associated with greywater (Oteng-Peprah et al., 2018). The high temperatures could be emanating from warm water used for cooking and personal hygiene. Certain carbonates, such as $CaCO_3$, and other inorganic salts that tend to be less soluble at high temperatures may precipitate because of these high temperatures (Oteng-Peprah et al., 2018). Additionally, the high temperature may further encourage microbial growth or development, which is unpleasant (Oteng-Peprah et al., 2018).

Studies postulate that the amount of total suspended particles in greywater can vary and typically fall within the range from 190 to 537 mg/L (Oteng-Peprah et al., 2018; Edwin et al., 2014). The relatively high values of total suspended solids (TSS) in greywater can be attributed to greywater mostly coming from sources such as laundry and kitchen due to the washing of vegetables, fruits, shoes, clothes, tubers and other things that tend to harbor clay, sand, and other substances that contribute to elevated levels of TSS (Oteng-Peprah et al., 2018).

Chemical Characteristics

Chemical oxygen demand (COD) and biological oxygen demand (BOD_5) are some conventional wastewater criteria used. The Chemical oxygen demand (COD) parameter has been found to take precedence over the biological oxygen demand (BOD_5) (Oteng-Peprah et al., 2018). The BOD_5/COD ratios regulate the biodegradability of greywater. The ratio establishes how readily the organic materials (matter) in the greywater can be broken down by microorganisms (microbes). It has been found that most greywater types exhibit good biodegradability as it relates to the BOD_5/COD ratios (Li et al., 2009).

Greywater Application, Treatment Technologies, and Black Water

As pressures on freshwater resources increase around the world and as new sources of supply become exorbitant, scarce, or politically controversial, efforts are underway to look for novel alternatives to meeting water demands (Allen et al., 2010). Recycling water in urban settings is the least developed among the several water reuse possibilities, including groundwater recharge, irrigation, and industrial (Pidou et al., 2008). Reusing rainwater, grey, or blackwater is typically incorporated into urban recycling (Pidou et al., 2008). Some of the most cost-effective methods minimize water demand by enhancing water efficiency and utilizing alternative water sources that were previously deemed unsuitable. Greywater and blackwater are usually blended in home wastewater streams and fit the description above (Allen et al., 2010).

Greywater has distinct characteristics from blackwater, which contains significant amounts of organic or fecal matter, urine, or industrial pollution. If greywater and blackwater can remain separated at the source, then resource recovery is significantly less difficult. Maintaining separation of domestic sewage into blackwater and greywater components is considered a key piece of efficient resource recovery from wastewater (De Gisi et al., 2016). As noted earlier, greywater is distinct from heavily contaminated "blackwater" (Allen et al., 2010). Compared to blackwater, greywater has more social acceptability and requires far less treatment to be viable for reuse due to its lower concentrations of contaminants (Kobayashi et al., 2020). Greywater can replace the uptake of potable water for non-potable applications such as garden irrigation, toilet flushing, laundry, outdoor uses, and sometimes showering (Allen et al., 2010). Other greywater administration, however, encompasses car washing, air conditioning, fire safety, the irrigation of parks, golf courses, schoolyards, and cemeteries (Pidou et al., 2008). Toilet flushing is amongst the most popular implementations of greywater reuse and can minimize water consumption in dwellings by up to 30% (Gross et al., 2007).

According to the United States Environmental Protection Agency, toilet flushing and outdoor uses such as irrigation/yard watering are some of the largest or highest water uses in homes (USEPA, 2025). From observation and research, these non–potable water uses do not necessitate that the water should be of the utmost quality like that of drinking water. Reusing greywater from dishwashers and kitchen sinks is not ideal because these sources tend to harbor heavy sums of organic materials, caustic additives, and fats at levels that make it difficult for soil organisms to break down.

The term greywater reuse can encompass numerous different systems and configurations, which may be as simple as DIY laundry-to-landscape systems or much more complex using multiple stages of mechanical treatment (San Francisco Public Utilities Commission, 2017). Grey water, which is usually defined as wastewater that does not emanate from toilets, thus wastewater from showers, bathtubs, hand basins, kitchen sinks, and laundry, is often largely treated in spread settlings or systems that are combined (Ottoson & Stenström, 2003). A settling tank, a sand filter trench, a soil infiltration system, or a subsurface flow wetland, which reduces thermotolerant coliforms by 0.7–3 logs, characterizes the spread settling treatment approach (Ottoson & Stenström, 2003). The technologies now in use were designed to treat or eliminate contaminants; they do not provide a comprehensive treatment of greywater (Oteng-Peprah et al., 2018). Given the variety of systems, logistical complexity, and costs, it is very important to have a baseline knowledge of the composition or characteristics of the greywater that will be reused to have a better sense of the most appropriate treatment technologies or techniques to employ. To ensure that the effluent from a greywater treatment system satisfies the necessary effluent standards, designing greywater systems that target specific recycling options while factoring in certain geographical complexities and differences will be a wise approach (Oteng-Peprah et al., 2018). In other words, the greywater treatment technology and final quality should correlate with its intended reuse purpose (Pachkor et al., 2017). According to Ajit (2016), specific greywater treatment should be tailored to household reuse needs since greywater characteristics vary from household to household.

Greywater treatment technologies are characterized by chemical, biological, and physical systems (De Gisi et al., 2016). Biological processes like Rotating Biological Contactor (RBC), Membrane Bioreactor (MBR), and Upflow Anaerobic Sludge Blanket (UASB) have been mainly harnessed to separate contaminants (organic matter) because they are very efficient. However, due to these technologies' mechanical nature, complexity, and cost, they tend to be more suited for centralized treatment systems. As part of the treatment process, it is important that suspended solids and turbidity be removed by physicochemical techniques such as coagulation and filtration to render greywater suitable for non-potable uses (Ajit, 2016). Due to the presence of dangerous bacteria, nutrients, viruses, and household chemicals in domestic wastewater that can contaminate water, land, and endanger public health, domestic wastewater needs to be adequately treated (Sudarsan & Renganathan, 2011). Although geography and use determine the water quality criteria for wastewater recycling, they typically include characteristics depending on the water's solid, microbiological, and organic components (Pidou et al., 2008).

For greywater to attain non-potable reuse standards, there is a need for biological treatment, physical treatment, and chemical treatment of the greywater. Light greywater can be effectively treated with chemical processes that are suitable for eliminating surfactants, organics, and solids. Additionally, aerobic biological processes are powerful to aid the removal of organics in dark and mixed greywaters that possess high organic strength. Physical processes, specifically membrane filtration, are usually recommended for polishing effluents after they have been biologically or chemically treated (Leong et al., 2017). Testing greywater for chemical, biological, and physical properties can assist in the identification of suitable purification pathways for specific reuse (Pachkor et al., 2017).

Environmental and Health Implications of Greywater Recycling

The prospect of reusing greywater has garnered significant attention, particularly in arid regions; nevertheless, there is a need for a thorough and systematic consideration of the potential risks associated with greywater reuse (Ottoson & Stenström, 2003). There are legitimate concerns for environmental and human health if greywater is improperly treated or handled (Maimon et al., 2010). Certain parameters of greywater, such as sodium, boron, and chlorine from surfactants, bleaches, and detergents, may lead to leaf cupping, alkalinity of the soil, discoloration of plants, block calcium ions from the reach of plants, or disrupt the capacity of soil to take up water by interfering with the osmotic pressure when their concentrations are high (James et al., 2016). Additionally, the accumulation of salts in the soil can lead to stunted growth and toxicity in plants. Greywater comprises of various chemicals employed in households, some of which may result in soil deterioration (Ottoson & Stenström, 2003). Site-specific factors should be considered. Minimizing pathogens in the aquifer and soil is a pivotal concern for safe management of water.

In terms of impact on the environment, overall, the environmental health risks from greywater are relatively low and are often seen to be outweighed by the positives of reduced water and energy consumption (Elhegazy et al., 2020).

The risks to human health include pathogen contamination via direct contact or consumption of contaminated plants improperly irrigated with greywater. Pathogens such as *Legionella pneumophila* and those associated with diarrheal diseases, as well as *gastroenteritis,* are the most common risks to human health. However, the risk threshold is relatively low, and threats can be addressed with simple monitoring, treatment, and management of greywater. However, it is not advisable to reuse untreated greywater, particularly within a multi-household system, because it may compromise public health (Maimon et al., 2010).

Social / Public Perception and Acceptance of Greywater

One research gap that has been identified is the public perception of greywater recycling. For a water management project or research, such as greywater, to be sustainable, community buy-in cannot be overlooked (Boufaroua et al., 2013). One of the central determinants of greywater recycling is social or public acceptance, as decentralizing greywater treatment down to the household means that individual homeowners or building managers must invest in and maintain treatment systems (Taher et al., 2019). Social support or public acceptance of water recycling is one of the biggest hindrances to the implementation of water reuse agendas. Even though greywater reuse is highly regulated and full of promise as a water management strategy, public acceptability has historically restricted the implementation of viable reclaimed water systems. Public opposition often originates from what is known as the “yuck factor,” which is the disgust originating from the perception of recycling sewage and the associated safety concerns (Garcia-Cuerva et al., 2016). In the absence of effective public involvement and acceptance, adopting and establishing techniques or mechanisms relevant to water reuse will be a herculean task and prone to failure (Maraqa et al., 2016). Educating the public and sensitization (awareness creation) in relation to greywater and its management is a major determinant in enhancing acceptance levels and attitudes of individuals towards greywater recycling.

Public perceptions of greywater utilization show signs of an inverse proportionality with the degree of physical contact (Maraqa et al., 2016). Reusing greywater as flush water has the highest social or public acceptance from studies. What are the characteristics of a person most likely to adopt greywater reuse, and the characteristics of a person least likely to adopt reuse? The economic status or standings of individuals have the tendency to influence people's decisions on greywater management (Taher et al., 2019). Financial incentives affect the willingness of respondents to engage in water reuse programs. Factors such as the last monthly water bill, age, location, and sex of participants do not have a significant influence on the acceptance of water reuse. On the other hand, the level of education, ethnicity, income, and metro/non-metro can greatly influence public perception (Garcia-Cuerva et al., 2016).

Source separation of domestic wastewater is one of the best strategies for reusing valuable substances in domestic wastewater; however, its implementation and success are heavily dependent on favorable public opinion and acceptance. According to Smol (2023), improved awareness and assistance from the public, water utilities, and policymakers are essential. There is a need for more efforts and interest to encourage the benefits associated with greywater reuse and to prevail over the regulatory and technical hurdles to the implementation and acceptance of greywater recycling. In other words, greywater reuse systems need to be easily obtained, installed, and maintained, low-cost, and above all, there should be no legal ambiguity.

Greywater Research and Gaps

The full implementation and advancement of greywater recycling are hindered by factors such as public perception, policies, and regulations. Numerous studies have focused on the characteristics of greywater, the various greywater treatment technologies (physical, chemical, and biological), the various non-potable uses or purposes such as watering gardens, yards, flushing toilets, washing vehicles, and, in some instances, bathing or showering. This cuts across a considerable number of studies and research papers. However, relatively few studies have focused on resource recovery, public perceptions of greywater, and regulatory requirements and policies that relate to greywater reuse. Research gaps authors have called out encompass insufficient system analyses that explicitly tackle decentralized greywater treatment across distinct scales, the social and economic impact of greywater treatment technologies, public sensitization to fuel a higher recognition of greywater, economic benefits of greywater recycling especially monetary gains to farmers and the community, instilling trust in greywater recovery across a wide variety of water users, developing procedures or strategies that will hamper the growth of pathogens like *L. pneumophila*, a revision of existing rules on greywater control to aid the establishment of a more flexible regulatory system capable of tackling the potential risks related to recycling greywater. Greywater reuse acceptance is not substantially documented by review articles and scientific studies, especially regarding low-income communities (Madzaramba & Zanamwe, 2023).

Research has shown that areas with favorable water supplies have been closely associated with the growth and development of human settlements since prehistoric times (Oteng-Peprah et al., 2018; Angelakis et al., 2018). However, research on user/public acceptance of greywater reuse in low-socioeconomic-status neighborhoods is lacking. The hunt for new water sources and their adoption/acceptance in more developed regions of urban settlements has been the focus of earlier/past research (Madzaramba & Zanamwe, 2023). Finally, applications of the systems in novel emergencies and transitional settings have largely not been studied.

Some Examples of Greywater Treatment Systems

The technologies now in use were designed to treat or eliminate contaminants; they do not provide a comprehensive treatment of greywater (Oteng-Peprah et al., 2018).

Greywater Treatment Systems (Oteng-Peprah et al., 2018).

- Rotating biological contactors (RBCs)
- Membrane Bioreactor
- Constructed Wetland
- Upflow Anaerobic Sludge Blanket
- Sequencing batch reactor (SBR)

Water, Sanitation, and Hygiene (WASH) and the Sustainable Development Goals (SDGs)

The Sustainable Development Goals (SDGs)

World leaders adopted the revolutionary 2030 Agenda for Sustainable Development ten years ago (United Nations, 2025). World leaders met at the United Nations and rendered an extraordinary commitment. An unprecedented commitment to transforming the world by 2030 with the goal of leaving no one behind. To tackle pressing global issues over the next 15 years, the world formally started implementing the 2030 Agenda for Sustainable Development on January 1, 2016, thus a revolutionary plan of action centered on 17 Sustainable Development Goals (United Nations, 2016).

Building on the achievements of the Millennium Development Goals, this agenda will serve as a road map to ensure long-term social and economic advancements for both people and the planet on a global scale (United Nations, 2016). In addition to eradicating extreme poverty, it aims to balance and integrate the environmental, economic, and social (three aspects of sustainable development) in a holistic global perspective/context (United Nations, 2016). Millions of individuals have now had access to basic services since 2015. More than half of people all around the world get to enjoy social protection in some capacity, a ten-percent point increase from ten years earlier (United Nations, 2025). The SDGs are not legally obligatory. Even though the goals are not legally binding, all countries are expected to develop a national framework to attain the 17 SDGs using their unique policies, programs, and plans (United Nations, 2014).

To fulfill the promise of the SDGs, local leaders, communities, civil society, and youth are putting in more effort and increasing action globally. Notwithstanding these significant advancements, climate disruption, economic shocks, geopolitical tensions, and conflicts still hinder progress at the level and speed required to reach the 2030 target (United Nations, 2025). Only 35% of SDG targets are on track or making moderate progress, according to the United Nations 2025 Sustainable Development Goals Report. A disturbing 18% are in retrogression, and almost half are moving too slowly. This is a critical point in human history, with only five years left to fulfill the Sustainable Development Goals (SDGs) since their establishment ten years ago (United Nations, 2025).

From all these years and times spent, it is evident that sustainable development is not a destination but rather a journey. A journey of adaptation, invention, and devotion to human dignity (United Nations, 2025). Despite significant progress on the SDGs, the rate of change is insufficient to meet the 2030 commitments. One out of every eleven people still experience hunger, and billions do not have access to safe drinking water, sanitation, or hygiene. Persistent disparities continue to restrict human potential, with women contributing 2.5 times as many hours per day to unpaid care work as men. Additionally, people with disabilities in a variety of areas/sectors are still underserved. There is an urgent need for global development. The year 2024 was the warmest/hottest year on record, with temperatures above the 1.5°C threshold. Additionally, carbon dioxide levels are at their greatest point so far in more than two million years. Climate change is accelerating, with temperatures shattering records year after year (United Nations, 2025).

None of the 17 SDGs will be accomplished globally by 2030, given the rate of advancement since the international community adopted the SDG Goals in 2015 (Figure 2). SDG 14 (Life Below Water), SDG 15 (Life on Land), SDG 11 (Sustainable Cities and Communities), SDG 16 (Peace, Justice, and Strong Institutions), and SDG 2 (Zero Hunger) are the most off-track goals on a global scale (Sachs et al., 2025). They face significant obstacles (highlighted in red on the dashboards) and have made little to no progress since 2015 (Sachs et al., 2025).

Figure 2:World SDG Dashboard with the 4-arrow system for representing SDG trends. Source: Sachs et al. (2025)

Several countries are experiencing unprecedented debt payment expenses (debt servicing costs), while a startling $4 trillion annual finance deficit stifles development progress. In the meantime, low-and middle-income nations' debt servicing expenses hit a record $1.4 trillion, limiting funds required for sustainable development (United Nations, 2025). According to the United Nations (2025), transformation is achievable when proven (evidence-based) tactics, policies are combined with political bravery and sufficient resources (investments) based on the evidence presented. With only a demi-decade left to meet the Sustainable Development Goals (SDGs) by 2030, development has been woefully inadequate.

Progress of SDG Targets

The world is still far from fulfilling the 2030 Agenda, according to the 2025 progress assessment of the United Nations. Global trend data from the 2015 baseline to the most current year has the capacity to evaluate 139 of the 169 SDG targets. This can then be further supported by custodian agency analysis. Among these,18 percent seem to be on track, 17% making modest advancement, with only 35 percent demonstrating sufficient improvement. Conversely, 48% of targets exhibit inadequate development, with 31% showing very slight improvements and 17% revealing no progress at all. The most alarming information revealed is that approximately 18% of the targets have fallen back below baseline levels from 2015 (Figure 3). Worldwide averages may obscure significant achievements in many nations that have achieved substantial progress toward multiple goals since this analysis focuses on global trends (Figure 4).

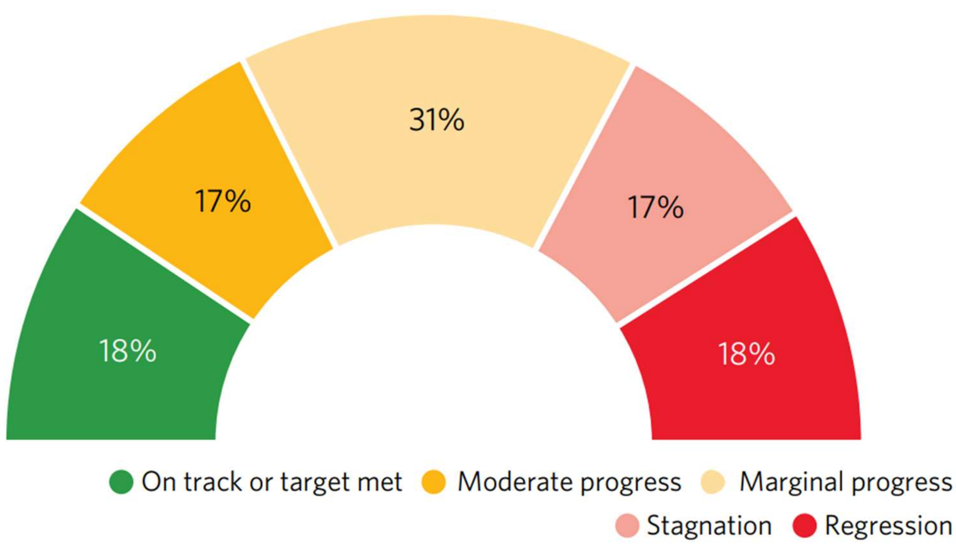

Figure 3: 2015 - 2025 global aggregate data depicting overall progress across targets. Source: United Nations (2025) SDG Report

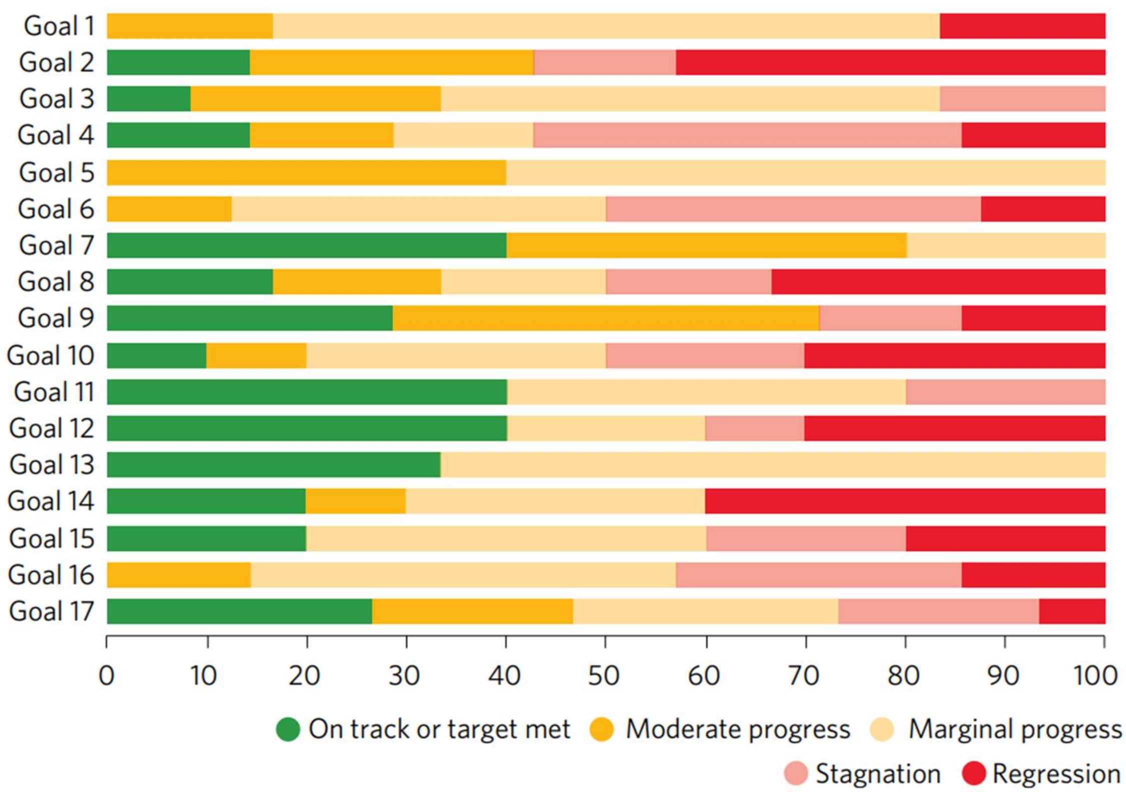

Figure 4:Assess Targets for the 17 goals - progress assessment of goals by goal percentage. Source: United Nations (2025) SDG report

Water, Sanitation, and Hygiene (WASH)

WHO and UNICEF (2021) indicate that access to water and sanitation is a fundamental human right. Safe drinking water, sanitation, and hygiene (WASH) are vital to the socioeconomic development, well-being, and health of communities. Despite worldwide efforts, the difficulty of ensuring safe access to WASH services lingers on, especially in low - and middle - income countries (Pradhan et al., 2025). The socioeconomic growth, well-being, and health of communities depend on safe drinking water, sanitation, and hygiene (WASH) (Wolf et al., 2022; Pradhan et al., 2025). These interconnected components are together known as WASH (Water, Sanitation, and Hygiene). According to the World Health Organization (2023), every year, about 1.4 million people die due to a lack of access to adequate drinking water, sanitation, and hygiene.

Safe WASH is essential as it performs a vital role in promoting regular schools and dignity, establishing resilient communities, and strengthening livelihoods (Bisung & Dickin, 2019).

The first two targets of the United Nations Sustainable Development Goal (SDG) 6, which intend to greatly improve water and sanitation on a global scale, also touch on the significance of WASH (Pradhan et al., 2025). The targets are known as SDG 6.1 and SDG 6.2. The SDG 6.1 aims to provide everyone with equitable and universal access to safe and affordable drinking water by 2030. Additionally, SDG 6.2 aims to end open defecation and provide universal access to sufficient and equitable sanitation and hygiene by 2030, with special regard to vulnerable populations or circumstances, including the needs of women and girls. It is a basic human right to have access to safe and clean drinking water (Pradhan et al., 2025). Having access to sanitary facilities (restrooms) and disposing of waste properly (safely) are two aspects of sanitation that aid in the avoidance of water contamination, among other advantages.

There are serious health concerns (hazards) associated with untreated waste and contaminated water (Pradhan et al., 2025). The prevention of water-borne illnesses correlates to ensuring that everyone has access to safe, reasonably priced, and sustainable WASH, which in turn is fundamental to international development (Pradhan et al., 2025). Despite tremendous efforts with WASH, global obstacles persist; thus, there are about 3.5 billion individuals without access to safe sanitation, 2.2 billion without even the most basic handwashing facilities, and another 2.2 billion individuals lacking access to safe drinking water.

WASH Accessibility

The United Nation (2025) highlight that between 2015 and 2024, access to drinking water, sanitation, and hygiene services increased steadily; nonetheless, billions of people are still left unattended to or deprived. In 2024, safely managed sanitation is still deficient for 3.4 billion people, basic hygiene services at home are still undersupplied for 1.7 billion individuals, and 2.2 billion people lack safely managed drinking water. Approximately 646 million children still need access to basic hygiene services in schools, necessitating a fourfold increase in progress should we want to successfully fulfill targets by 2030. Water stress, pollution, and poor governance are putting pressure on water systems. There has been inadequate transboundary cooperation, freshwater ecosystems are deteriorating, while water stress is still a major issue in several areas, with only 56% of household wastewater being safely handled (United Nations, 2025). Women and girls suffer disproportionately from a lack of WASH. The lack of WASH restricts their access to education, employment, and community involvement. This further contributes to stress and anxiety (Bisung & Dickin, 2019).

The United Nations (2025) postulates that sustainable water management will not be achieved/possible globally until at least 2049 (Figure 5) should current trends persist. To attain the SDG Goal 6, innovative technologies must be leveraged, water management must be consolidated across all governance levels and sectors, institutional capacity must be reinforced, multi-stakeholder partnerships must be encouraged, and comprehensive financial mechanisms must be mobilized.

WASH Access in low-income communities - Vulnerable communities

According to WHO and UNICEF (2021), several individuals in low-income communities lack access to acceptable clean water and improved sanitation, even though these resources are essential human rights. Furthermore, 3.6 billion people globally lack access to safely managed sanitation facilities, and more than 2.2 billion people still lack access to safe drinking water. Should this sector's progress keep up its current pace, 1.6 billion people will lack access to safe drinking water while 2.8 billion people will lack adequate sanitary facilities by the year 2030 (WHO & UNICEF, 2021). These issues are particularly pronounced in low-income areas, characterized by a lack of access to infrastructure for water and sanitation, which in turn exacerbates already-existing disparities and endangers the health of populations (Armah et al., 2018).

It is therefore evident that low-income populations worldwide are facing severe challenges pertaining to improved sanitation and access to acceptable clean water. The adoption of Sustainable Development Goal 6 (SDG6) by the United Nations seeks to improve universal access to water and sanitation for all by 2030, with countries pledging their commitment. However, given climate change coupled with limited access to water and sanitation facilities, achieving SDG 6 in low-income communities would undoubtedly take longer than expected (Madzaramba & Zanamwe, 2023). Recycling greywater to supplement water supplies and enhance sanitation in low-income areas is one possible strategy to get beyond this obstacle (Vergine et al., 2017; Ibekwe et al., 2018; Ofori et al., 2021).

WASH Challenges in Schools

Access to key water, sanitation, and hygiene (WASH) services continuously improved around the world between 2015 and 2024. Coverage of safely managed sanitation improved from 48 to 58 percent, the percentage of people utilizing safely managed drinking water increased from 68 to 74 percent, and the coverage of basic hygiene services shifted up from 66 to 80 percent. Despite these advancements, there are still substantial obstacles. Access to WASH in schools is still at a level that is inadequate to guarantee equitable and safe learning environments. Even though 77% of schools provided basic sanitation and 77% offered basic drinking water services in 2023, 427 and 447 million students still lacked access to these vital facilities and necessities in that order. The current rate of progress will have to be doubled to achieve universal coverage by 2030. Schools offering basic hygiene services make up surprisingly only 67 percent of the whole, which implies that a fourfold increase in progress is required to make up for the 646 million children that are still underserved (United Nations, 2025).

Water Quality Monitoring and Measurements

Almost without any alterations from 2020, 56 percent of the domestic wastewater produced worldwide, thus 332 billion m^3, was adequately treated in 2024. This result or information is further supported by data from 12 territories and 130 Member States, when combined, account for 84% of the world's population. However, only 22 countries have reported data on industrial wastewater, making this information in this regard very limited. An all-encompassing worldwide reporting on wastewater is not anticipated to be available until 2027. Monitoring of water quality has improved. For instance, unlike 2020, when about 89 countries reported, there has been an increase in reporting for 2023 from 89 to 120. Substantial discrepancies in monitoring still exist despite these advancements (United Nations, 2025).

Only 60,000 of the 2 million water-quality measurements collected worldwide were employed by the nations that constitute the lower-income half of the world. This leads to key knowledge gaps about the effects of biodiversity loss, pollution, and climate change, thereby endangering the livelihoods and health of up to 4.8 billion people by 2030. National authorities in situ data collection are salient, but there are other advances like citizen science and satellite-based Earth observation. For instance, citizen-generated data has already been employed for reporting in Zambia and Sierra Leone. Additionally, other nations are following suit to fill data shortages with these innovations (United Nations, 2025).

Water Stress and IWRM Management

The implementation of integrated water resources management (IWRM) has increased from 49% in 2017 to 57% in 2023, but global development on integrated water resources management (IWRM) is still lagging (Figure 5). Additionally, 73 countries (40 percent) are falling behind, whereas 47 countries (26 percent) have achieved or are nearly at the "very high" implementation target. About 70% of nations indicate insufficient money for subnational water management. Also, 60% of countries lack effective revenue-raising strategies and systems. Till date, insufficient finance is still a key obstacle for the management of water. There is unrealized potential in strengthening the connection between IWRM and climate adaptation; nevertheless, there are still gaps in funding, coordination, and capacity.

Only half of the countries report formal agreements, depicting that cross-sector coordination is still difficult despite strong political commitments. Global ratings increased somewhat from 54% in 2020 to 58% in 2023, demonstrating moderate progress on gender mainstreaming in water management. However, 31% of nations reported poor implementation, and 15% of countries do not possess any gender procedure/mechanisms.

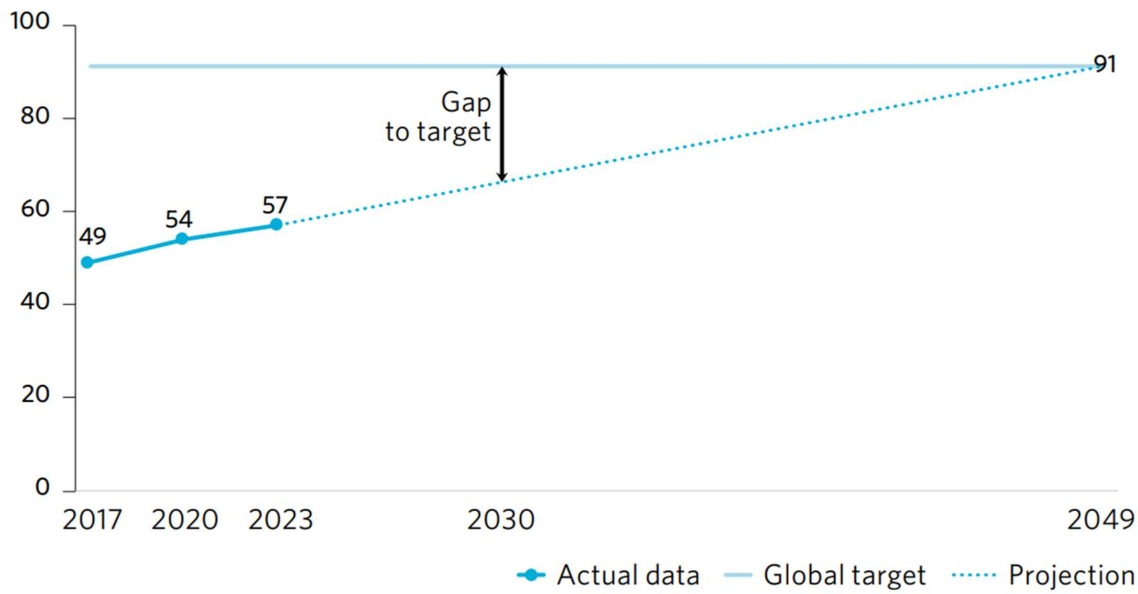

Figure 5:2017–2023 IWRM implementation global progress, projected to 2049 as a percentage. Source: United Nations (2025) SDG Report

Regional differences are glaring; nonetheless, global water stress remained stable at 18 percent in 2022, an unaltered percentage from 2015 (United Nations, 2025). Critical water stress levels surpassed 75 percent in many countries in Western Asia, Central and Southern Asia, and Northern Africa. Since 2015, water stress has also risen by an alarming 12% in Western Asia and Northern Africa (Figure 6). Approximately 10% of the world's population is currently experiencing high or critical water stress (United Nations, 2025). The economic sectors have a significant impact on the magnitude of water stress. Agriculture was responsible for 72 percent of the world's freshwater withdrawals in the year 2022, services at 13 percent, and industry coming in at 15 percent (United Nations, 2025). Agriculture is crucial for both economic expansion and food security; however, it is a casualty and contributing factor of water stress, hence rendering it one of the most susceptible industries to water stress (United Nations, 2025).

There is a need for increased agricultural water use efficiency, regulatory reforms, smarter water management, and strategic investments to tackle water stress (United Nations, 2025). Furthermore, temporal and subnational data are required to identify and reveal hidden vulnerabilities and direct focused action (United Nations, 2025).

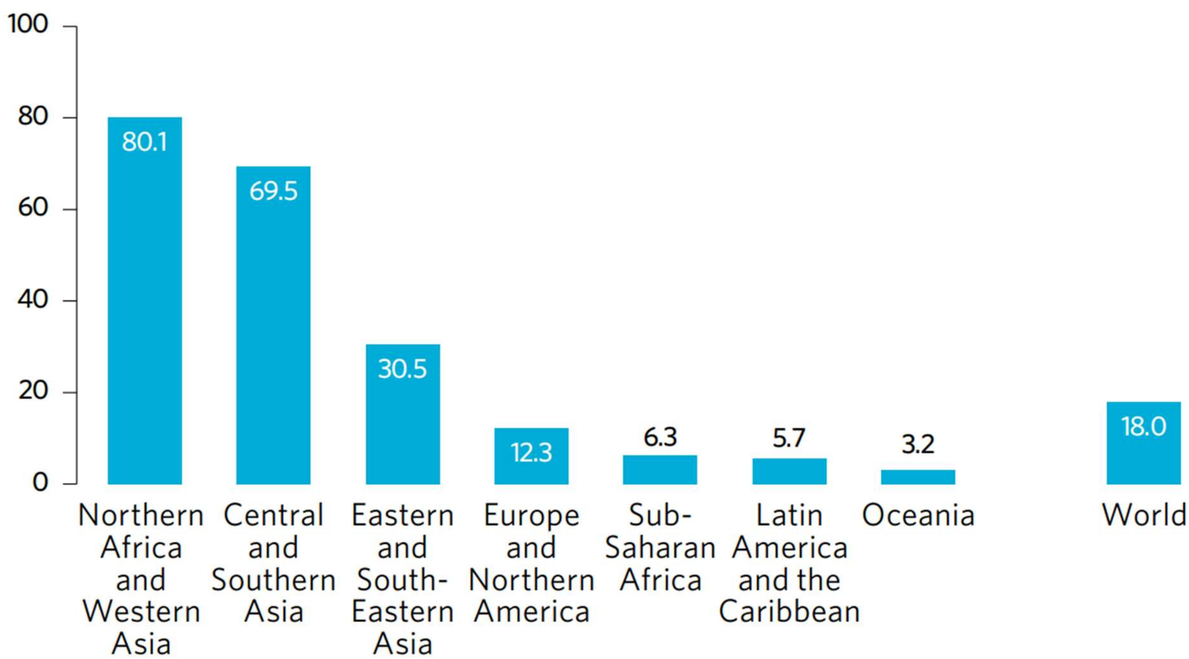

Figure 6: Water Stress Levels as a percentage for the year 2022. Source: United Nations SDG Report (2025)

Degradation of Water-Related Ecosystems

Degradation of freshwater ecosystems endangers livelihoods, biodiversity, and food security. About twenty-five percent of freshwater fish species are in danger of going extinct, including eighty-three percent of freshwater species populations have reduced since 1970 (United Nations, 2025). Sixty-one percent of nations reported and indicated that at least one or more categories of water-related ecosystems was damaged in 2015. However, between 2017 and 2021, this percentage decreased to 31% from 61 percent which is good news. Updated statistics on water quality, however, revealed less improvement, bringing the proportion back up to 50%. Significant regional differences persist (United Nations, 2025). About 21% of countries in Oceania report degradation, which is nowhere close to the over 60% of nations in Central Asia, Sub-Saharan Africa, and South-Eastern Asia that indicate that there has been some form of degradation (United Nations, 2025). The difference is vast.

More than 93 million individuals have been impacted by permanent surface water loss in 364 river basins owing to climate change and unsustainable practices (United Nations, 2025). There has been growth in the utilization of Earth Observation Data (United Nations, 2025). Nonetheless, only one-third of nations maintain national wetland inventories, which impedes the quality and employment of national data. Urgent funding (investment) for evidence-based policy, digital monitoring, and capacity building will be crucial to halt degradation and thus restore and protect freshwater ecosystems (United Nations, 2025).

Global Water Efficiency

Global water-use efficiency went up by 23% between 2015 and 2022, from $17.5/m^3 to $21.5/m^3, depicting increases in economic output without proportional gains in water use. Nonetheless, 57%

of nations continue to operate below the \$20/m^3 global benchmark. There are still notable regional differences. While Southern and Central Asia had the lowest efficiency levels (United Nations, 2025). North America, Oceania, and Europe, however, exceeded the world average. Total water withdrawal stayed relatively constant, which indicates that economic development was mostly responsible for the overall improvement. Sectoral patterns indicate that agricultural withdrawals stayed constant, municipal water use surged by 10% with industrial use decreasing by 5%. In 2022, efficiency differed significantly from one sector to the other, with industry achieving \$38.5/m^3, services attaining \$114.4/m^3, with agriculture achieving a mere \$0.7/m^3. Agriculture demonstrated the largest relative gain, thus a 39.5% improvement during the period, even though the baseline is low. Water-stressed areas must increase efficiency, especially regarding agriculture (United Nations, 2025). To see this in effect, institutional capacity-building, improved governance, and regulatory frameworks, in addition to innovations in technology, will be needed.

Disaster Impacts and Climate Vulnerability

Due to patterns of development and more severe hazards that render people more exposed and vulnerable, the risk of disasters keeps rising (United Nations, 2025). Although reported direct economic losses currently average $202 billion annually, the total losses exceed $2.3 trillion when ecosystem degradation and cascading impacts are taken into consideration. These growing expenses raise dependence on humanitarian aid, decrease income, elevate uninsurability, and deepen debt (United Nations, 2025). Extreme heat has become a serious hazard together with floods, earthquakes, droughts, and storms; thus, these are the five disaster categories that have caused almost all documented direct losses over the past 20 years. Furthermore, no nation is an exception (United Nations, 2025).

However, the number of people impacted by natural disasters has increased. At an average of 124 million impacted individuals annually, the rate of affected individuals increased by 75% to 2,028 per 100,000 (United Nations, 2025). This indicates that, despite fewer fatalities, people are becoming more exposed and vulnerable. Reducing losses requires early-warning systems and disaster risk reduction techniques (United Nations, 2025).

In 2024, the World Meteorological Organization (WMO) revealed that the average worldwide temperature was 1.55°C higher than pre-industrial levels. The year rounded off approximately 10 years of record-breaking temperatures (2015-2024) and was the warmest year in 175 years. Natural disasters in 2024 alone devastated every region just in the first half of the year (United Nations, 2025). Just one year exceeding 1.5°C, however, does not necessarily indicate that the Paris Agreement threshold has been flouted or violated. The present warming is projected to be between 1.34°C and 1.41°C over pre-industrial levels, regarding long-term patterns in climate change (United Nations, 2025). However, irreversible climatic repercussions are already being experienced across the world (United Nations, 2025). Record-breaking rates of glacier melting imply that many are unlikely to survive this century, posing a threat to long-term water security and leading to short-term hazards (United Nations, 2025).

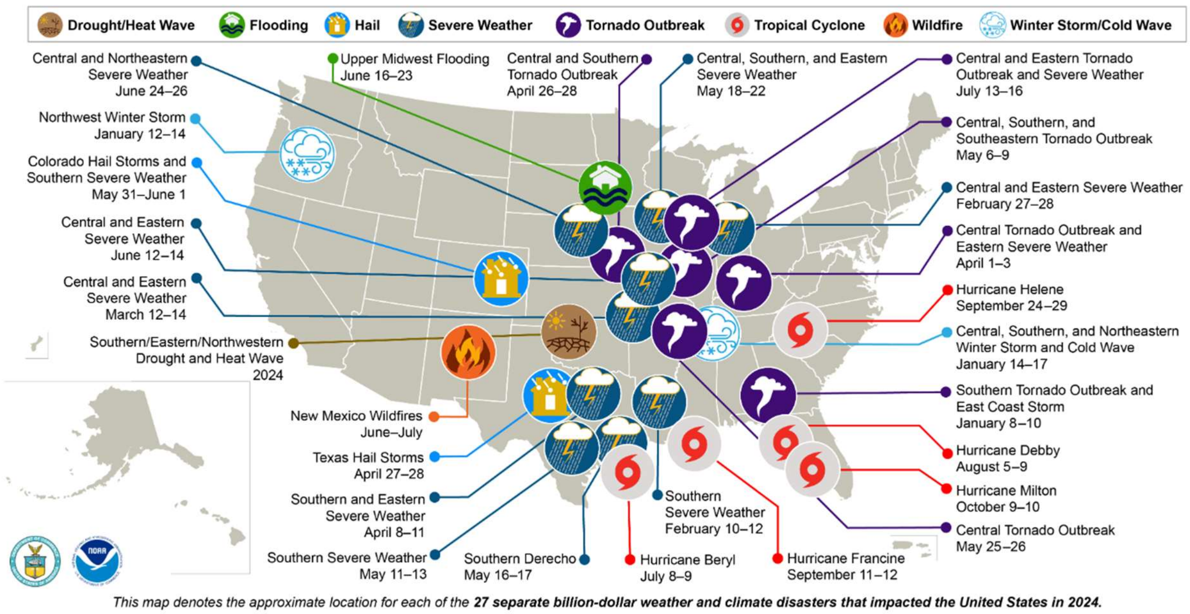

Figure 7: Billion-Dollar Weather and Climate Disasters for the US (2024). Source: NCEI National Centers for Environmental Information (2025)

Rising Temperatures and Climate Change

With 2024 being the hottest year on record and temperatures rising by about 1.55°C beyond pre-industrial levels, climate change is rapidly increasing. Food shortages, instability, and economic losses are all becoming worse owing to an increase in extreme weather. Additionally, extreme weather is causing the largest displacement caused by climate change in 16 years (United Nations, 2025). Although a year above 1.5°C does not constitute a violation of the Paris Agreement, it is a stark reminder that present international efforts are lagging on certain expectations and requirements. Also, it tells us that action and ambition must be reinforced in these crucial times (United Nations, 2025).

The world's efforts to combat climate change cannot and must not stall. Urgent investment in resilience, adaptation, and emission reductions must speed up, particularly in vulnerable areas, if we want to limit the 1.5°C warming target within reach. The time frame for securing a sustainable, livable future is fast closing, and the cost of doing nothing is significantly higher than the cost of taking action (United Nations, 2025). The year 2025 will mark the halfway point of a vital decade for reducing greenhouse gas emissions and ten years since the Paris Agreement, and hence it is a critical year for climate action. Aside from that, nations have until this year (2025) to submit their most recent nationally determined contributions (NDCs 3.0) or national climate plans, along with targets that span the year 2035. So far, only 25 nations have successfully tendered in their revised plans as of June 2025 (United Nations, 2025).

Greywater Recycling as a Means of Empowerment and Bridging Water Access Inequity

Women and girls suffer disproportionately from a lack of WASH. The lack of WASH restricts their access to education, employment, and community involvement. This further contributes to stress and anxiety (Bisung & Dickin, 2019). Globally, there are accessibility challenges to household water connections in lower-income communities. Often, children and women bear the brunt of traveling long distances or joining queues to get water and carrying it back home (Allen et al., 2010). The water that is accessed this way is highly cherished, given the level of effort invested and the extra strain it puts on the income of the household.

The water is usually recycled at home and channeled for horticulture or household gardens. The recycling of greywater can thus be an avenue for empowerment. Events in Jordan, Palestine, and Lebanon show that women oversee water management at the household level in several rural areas of the Middle East (Allen et al., 2010). The International Development Research Centre (IDRC) executed a greywater reuse pilot project in Tannoura, Lebanon, which is highly water-stressed.

The project was shown to greatly reduce the burden of water provision on vulnerable elements of the population, such as women and children (Allen et al., 2010).

CHAPTER III – GREYWATER TREATMENT IN TRANSITIONAL HOUSING COMMUNITIES

METHODOLOGY

An extensive literature review and search (secondary data) on greywater was conducted for chapter two in this thesis. I used the following keywords: greywater, graywater, *E. coli*, water and sanitation, WASH, water scarcity, homelessness, houselessness, soil, environmental justice, water reuse, and sustainable development, to search for literature on greywater research. Additionally, primary data collection methods (fecal indicator bacteria testing) were performed by the researcher.

Greywater Sampling and Testing Procedure

Researchers collected multiple greywater samples from each of the multiple CSS transitional housing communities (Figure 8). The purpose of the greywater sampling was to understand the levels of contamination of fecal indicator bacteria (FIB) such as total fecal coliforms and, more specifically, *Escherichia coli* within the greywater planters. *FIB,* such as *E. coli,* help to quantify water quality and the presence of fecal matter, which are threats to human and environmental health. Moreover, the level of contamination will determine what type of greywater reuse is permitted with the current planter system and whether additional treatment and disinfection processes and technology are necessary. The testing procedure, IDEXX Colilert, is a system that is widely utilized by water and wastewater utilities globally for *FIB*.

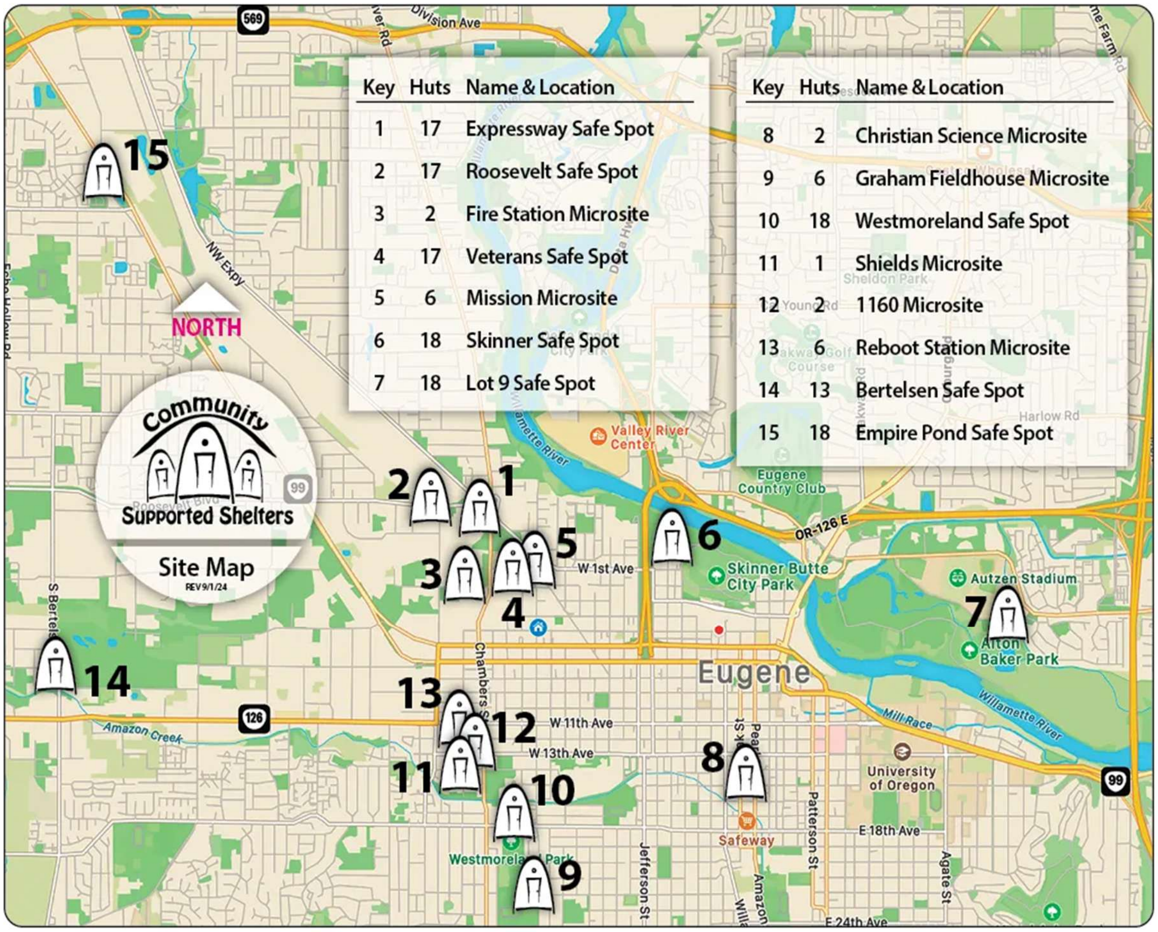

Figure 8:Locations of five sites where greywater planters have been constructed. Source: CSS website (https://www.communitysupportedshelters.org/)

Water quality results (*E. coli* and total coliforms) with the IDEXX Colilert are ready within a period of 24 hours. A sterile 100 ml container was used to sample the greywater at the study sites. The time of water sampling and the sampling site were recorded. The sampled greywater was carefully stored on ice and then taken to the lab for processing within six hours from the time of sampling. A reagent, the Colilert, was carefully added to the water sample and uniformly mixed with the water. The greywater was then poured into a quanti-tray. The quanti-tray was then inserted into a quanti-tray sealer and transferred to an incubator for 24 hours. The sampling results were then read and recorded.

Microbial water contamination testing was conducted for *total coliforms* and *E. coli* at two locations within each of the greywater planter systems (Figure 9). Sampling of all constructed systems was conducted 44 times, starting in June 2024 through to December 2024. It is important to reiterate this testing was not meant to be statistically significant but simple to understand the general water quality within the planter systems. Additionally, one of the systems (Mission Micro) had a biosand filter attached to it and samples were taken of the filtered water. Lastly, all sampling was accompanied by control samples and environmental samples which allowed the researcher to know that the sampling process was not contaminated and to provide an environmental comparator. The environmental samples were taken from the Mill Race, an artificial side channel of the Willamette River on the University of Oregon campus.

- Untreated greywater (Inlet)
- Water after filtering through one greywater planter (Outlet)
- Environmental samples taken from a waterway on campus (for comparison)
- Bio-sand filtered greywater.

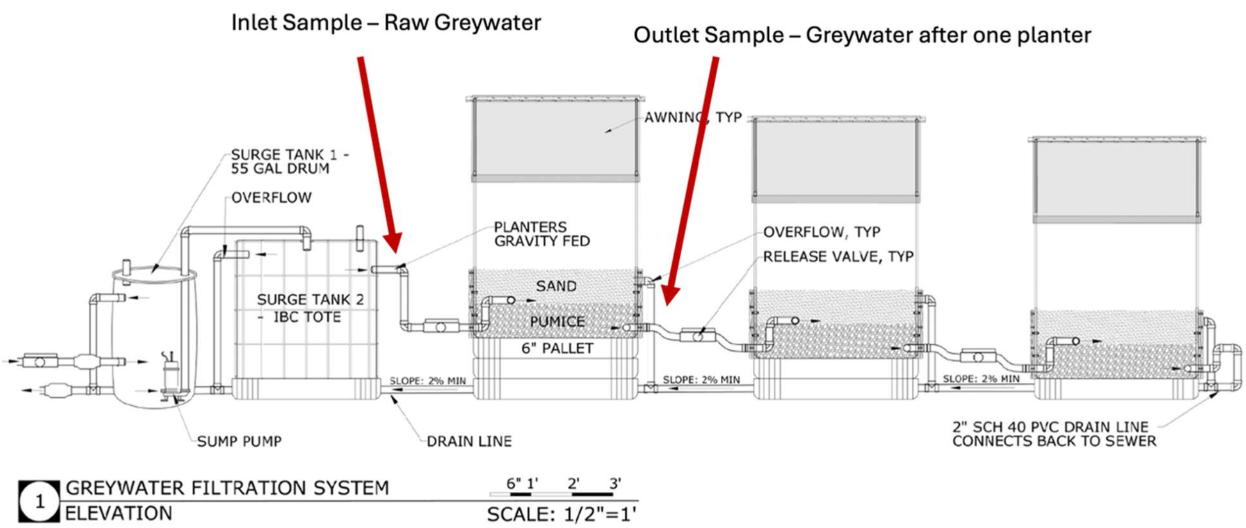

Figure 9: Schematic drawing of greywater planter system. Source Sam Alig University of Oregon Master's Thesis 2021

Study Sites

Table 1: Sampled Greywater Evapo-transpiration Systems

Community Name	# on Map	Construction Date	Type of system
The Skinner Butte Community	6	Constructed Spring 2021	Three planters where the greywater is currently evapo-transpirated.
Mission Micro Site	5	Constructed Winter 2024	The site has a single greywater planter and a biosand filter as

			well as a gardening bed
Lot Nine	7	Constructed Spring 2024	Three planters where the greywater is currently evapo-transpirated.
Westmooreland	10	Constructed Spring 2024	Three planters where the greywater is currently evapo-transpirated.
Expressway	1	Constructed Fall 2024	Three planters where the greywater is currently evapo-transpirated.

Greywater Modular Planter System Design, Operation, and Implementation

The greywater planter system consists of constructed modular greywater filtration planters specifically designed to serve temporary housing communities in Eugene, Oregon, that do not possess sufficient and reliable water infrastructure. The idea behind the construction is to develop a planter system that can evapo-transpirate the greywater and thus reduce or eliminate trucking away water from the houseless communities.

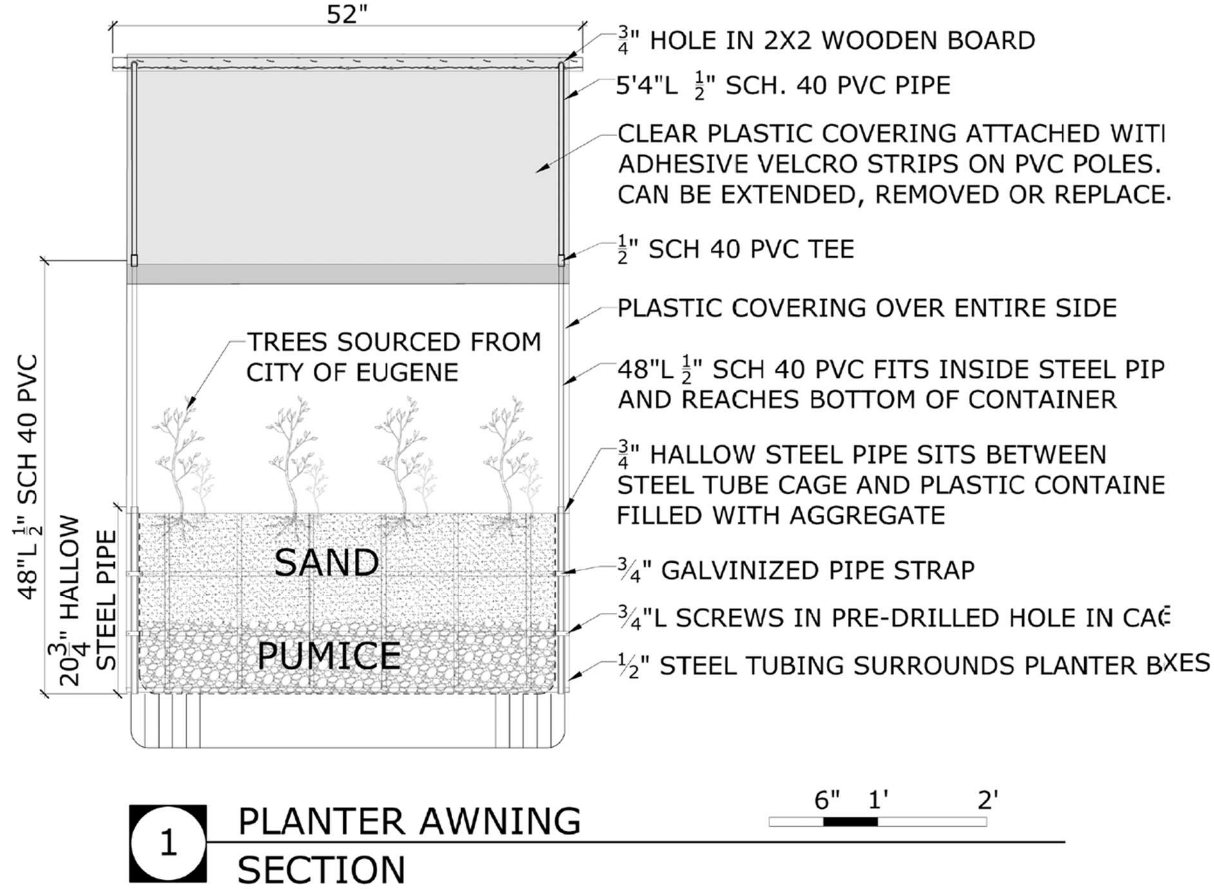

Figure 10 : A single greywater planter, systems can consist of as many planters as is needed to evapo-transpirate all the greywater produced at a given site. Source Sam Alig Master's Thesis 2021

The Modular Greywater system at the study sites is characterized by repurposed Intermediate Bulk Containers (IBCs), including a clumping bamboo or wetland plants serving as phytoremediation agents (Figure 10). The system is intended to receive greywater emanating from sources such as the communal kitchen and handwashing sinks. The planters' design, thus consisting of natural materials, helps provide an efficient, sustainable, community-focused greywater filtration system. The system is an amalgamation of soil-sand substrates, internal piping, external piping, wood framing, and clumping bamboo. Before this greywater system was constructed at the study sites, water was trucked daily out of the site/community to be disposed of at the municipal wastewater treatment facility. This study monitors modular greywater planters at specific transitional housing communities in Eugene.

For a complete description of the construction of the greywater planter system, see the Greywater Planter Manual (https://www.koryrussel.com/_files/ugd/cd823e_3c0391268d624245983487c39bbbcdf8.pdf).

CHAPTER IV

RESULTS

After water collection and analysis, the greywater sampled tested positive for fecal indicator bacteria, both total coliforms and *E. coli*. From the results, it was observed that the sampled water in the quanti-tray changed to a yellow color, which helped inform this decision. The yellow coloration indicates the presence of total coliforms. Hence, the sampled greywater tested positive for total coliforms. The researcher also observed that the wells in the quanti-tray possessed fluorescence when passed under Ultraviolet light/radiation.

The yellow coloration, coupled with fluorescence signals, strongly that there is the presence of *E. coli*. Despite this, results and follow-up from the test conducted suggest that the greywater systems substantially reduced *E. coli* but not so much total coliforms. While this might seem to be little consolation in terms of total coliforms, it is worth noting that the system is reducing the most pathogenic material, which is a step in the right direction. Experimentation with treatment methods, practices, and methodologies is ongoing to see to the best treatment and handling practices for greywater to eliminate major pollutants and ensure that the recycled water can be utilized for non-potable reuse (Halwani et al., 2018).

FIB samples from the Constructed Systems

The three tables below lay out the results of the testing. In Table 1, all the samples regardless of location or site tested positive for total coliforms and were too numerous to count.

Table 2: Mean and Median MPN/100ml Total Coliform test results for several types of samples (>2419.6 indicates that all wells on the quanti-tray were positive and thus MPN/100ml is too numerous to count).

Sample Type (n)	**Mean Total Coliforms (MPN/100ml)**	**Median Total Coliforms (MPN/100ml)**
Inlet (18)	>2419.6	>2419.6
Outlet (10)	>2419.6	>2419.6
Environmental Samples (3)	>2419.6	>2419.6
Biosand (3)	>2419.6	>2419.6

In table 3 we see that the median *E. coli* levels are much higher in the inlet greywater samples (102 MPN/100ml) than in the outlet samples (0.5 MPN/100ml). The mean numbers for *E. coli* as heavily skewed by two, too numerous to count, samples.

Table 3:Mean and Median MPN/100ml E. coli test results for several types of samples

Sample Type (n)	**Mean *E. coli* (MPN/100ml)**	**Median *E. coli* (MPN/100ml)**
Inlet (18)	231	102
Outlet (10)	484	0.5
Environmental Samples (3)	169.5	125
Biosand (3)	1	1

Table 4: Comparison of inlet and outlet samples from all sites, taken at the same date and time, for total coliforms and E. coli MPN/100ml.

Site	**Total Coliform MPN/100ml**	***E. coli* MPN 100/ml**	**Date**
Expressway Inlet	>2419.6	1	12/30/24
Expressway Outlet	>2419.6	0	12/30/24
Lot 9 - Inlet - 1	>2419.6	9.6	6/8/24
Lot 9 - Outlet - 1	>2419.6	2419.6	6/8/24
Lot 9 - Inlet - 2	>2419.6	0	11/24/24
Lot 9 - Outlet - 2	>2419.6	0	11/24/24
Lot 9 Inlet - 3	>2419.6	2419.6	11/28/24
Lot 9 Outlet - 3	>2419.6	128.1	11/28/24
Lot 9 Inlet - 4	>2419.6	0	12/30/24
Lot 9 Outlet - 4	>2419.6	1	12/30/24
Mission Micro Inlet	>2419.6	2	11/24/24
Mission Micro Outlet	>2419.6	0	11/24/24
Skinner Butte Inlet	>2419.6	0	12/30/24
Skinner Butte Outlet	>2419.6	0	12/30/24
Westmooreland Inlet	>2419.6	2	12/30/24
Westmooreland Outlet	>2419.6	0	12/30/24

In general, the outlet samples have less E. coli contamination than the inlet samples, but there are exceptions such as Lot Nine on the 6/8/24 and 12/30/24. The greywater planters have no impact on total coliforms as these remain too numerous to count both before and after the greywater planter.

CHAPTER V

DISCUSSION OF RESULTS

This section delves into results interpretation, performance evaluation of the system, design scalability and replicability, water quality parameters, etc.

Traditional wastewater infrastructure is usually unfeasible in unhoused communities due to complexity, cost, and even the location of these communities. As such, transitional housing communities lack the infrastructure for reliable water access and management. The greywater modular planter system was built successfully and installed within the target community, thus transitional housing communities in Eugene, Oregon. These systems are accomplishing their original goal which is to significantly reduce the amount of greywater that must be trucked away.

The prospect of reusing greywater has garnered significant attention, particularly in arid regions; nevertheless, there is a need for a thorough and systematic consideration of the potential risks associated with greywater reuse (Ottoson & Stenström, 2003). Coliform bacteria and *E. coli* are the most utilized indicators of fecal contamination (Oteng-Peprah et al., 2018). It is expected that fecal contamination in greywater be low (Ottoson & Stenström, 2003). Activities, such as washing feces-contaminated clothes, such as diapers, including showering, and childcare, may result in tiny amounts of feces in greywater (Ottoson & Stenström, 2003). Due to greywater making up a significant fraction of the actual wastewater flow, nonetheless, possessing minimal fecal contamination, with local systems lacking the capacity for its reuse, its high-grade treatment has come under scrutiny (Ottoson & Stenström, 2003).

Greywater may include a higher amount of readily degraded organic material, which has the potential to support the growth of enteric bacteria like fecal indicators. There have been reports of such growths taking place in wastewater systems (Ottoson & Stenström, 2003). Owing to this, focusing on bacterial indicator counts will result in an overestimation of fecal burdens and associated risks (Ottoson & Stenström, 2003). Several studies have indicated high levels of traditional fecal markers/indicators in greywater, which translates to significant fecal contamination from a regulatory angle/viewpoint (Ottoson & Stenström, 2003). It is crucial that possible indicators/markers of regrowth and actual fecal loads be distinguished, so as to be able to evaluate actual risks of greywater reuse more accurately (Ottoson & Stenström, 2003).

A temperature range of typically between 18 to 35 degrees Celsius is associated with greywater (Oteng-Peprah et al., 2018). The high temperatures could be emanating from warm water used for cooking and personal hygiene. Certain carbonates, such as CaCO3, and other inorganic salts that tend to be less soluble at high temperatures may precipitate because of these high temperatures (Oteng-Peprah et al., 2018). Additionally, the high temperature may further encourage microbial growth or development, which is unpleasant (Oteng-Peprah et al., 2018). Studies postulate that the amount of total suspended particles in greywater can vary and typically fall within the range from 190 to 537 mg/L (Oteng-Peprah et al., 2018; Edwin et al., 2014). The relatively high values of total suspended solids (TSS) in greywater can be attributed to greywater mostly coming from sources such as laundry and kitchen, due to the washing of vegetables, fruits, and shoes.

Observed patterns suggest that total coliforms MPN/100ml for all samples was uniformly high and too numerous to count. Outlet *E. coli* MPN/100ml samples tended to be lower than inlet samples with one or two exceptions. This is a positive outcome but does not allow greywater reuse (type 2) without further treatment or disinfection. In general, the greywater that had passed through one greywater planter was less contaminated than the environmental samples (Mill Race) for *E. coli* but not total coliforms. Lastly, the biosand filter appears to be maintaining low *E. coli* contamination levels but not reducing total coliforms.

The risk to human health is determined by the type of treatment, the pathogen's source, and exposure pathways (Ottoson & Stenström, 2003). Because of the potential for regrowth of coliform indicator bacteria within the system, associated risks/hazards may be magnified. (Ottoson & Stenström, 2003). If the greywater system under investigation is assessed based on the traditional indicator bacteria study, the conclusion is that a significant, albeit extremely variable, fecal input occurred, which is in line with already available research/studies. Nevertheless, bacterial indicator growth, especially from the coliform group, may take place in the system, significantly overestimating the fecal burden of greywater.

This type of growth has been recorded in a variety of identical systems stemming from the organic carbon breakdown (Ottoson & Stenström, 2003). Conventional bacterial pathogens such as Salmonella and fecal coliforms regrowth takes place without difficulty (Ottoson & Stenström, 2003). Growth of these and other bacterial pathogens, including *E. coli* O157:H7, can grow on vegetables that have been stored unsuitably, leading to significant input due to kitchen handling in greywater systems. Chemical biomarkers are another approach that can be used to assess fecal contamination. (Ottoson & Stenström, 2003).

Evaluation of Greywater Modular Planter System Treatment Effectiveness

Before these greywater systems were constructed at the study sites, water was regularly trucked out of the site/community to be disposed of at the municipal wastewater facility. This process imposes logistical, economic, and environmental burdens. Having a greywater planter system at the sites has helped reduce truck hauling of wastewater which is unsustainable on many levels. However, this system of planters does not treat the greywater to a level that is legal to be discharged or reused for non-potable uses such as irrigation above ground (type 2 greywater reuse OR DEQ).

The treatment efficiency of the investigated system was non-detectible for total coliforms, and while it did reduce *E. coli* contamination, it did not eliminate it from the greywater planter system, and this includes the biosand filters.

Because of certain limitations, like irregular frequency of water flow and site accessibility, and uneven site distribution for data collection, this study was not attempting to reach statistical significance but merely to characterize and understand the contamination levels in the greywater planters and on-site. Greywater monitoring confirmed high levels of contamination, including *E. coli*. This is likely due to the primary source of greywater in all sites originating in the shared kitchen facility. Contaminated greywater that is directly released to the environment can result in ecological harm and water contamination when it is not recycled on-site (Madzaramba & Zanamwe, 2023). Results from the study exhibit that this system is economically feasible, community-oriented, environmentally friendly, flexible, innovative, adaptable, expandable, and reproducible, especially for underserved populations. Although not perfect, this system is a great step towards sustainability, especially SDG 6. However, to reuse the greywater for type 2 or 3 applications, there will be a need for further filtration and chlorination.

Research Questions Answered

1) Is there total coliform and *E. coli* contamination of the initial greywater before it enters the greywater planters?

   - Yes, the initial greywater had high levels of total coliforms and typically at least some *E. coli* contamination.

2) Is there total coliform and *E. coli* contamination of the greywater after it has passed through one greywater planter?

   - There was no reduction in total coliform contamination after passing through one greywater planter. However, there was typically some reduction in *E. coli* contamination, though not 100% of the time.

3) Did initial tests of biosand filter reduce contamination of total coliform and *E. coli* contamination?

   - There was no reduction in total coliform contamination after passing through the biosand filter. However, there was typically a reduction in *E. coli* contamination, though it did not eliminate the *E. coli* contamination.

4) Is the current greywater planter system sufficiently treating the water to type 2 reuse standards?

- No, the current greywater planter system is not sufficient to reuse greywater for type 2 activities. Further, treatment and disinfection processes or technologies will need to be added to the system.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

This modular greywater planter system highlights a practical approach to onsite greywater treatment with potential to enhance greywater recycling, thereby enriching living conditions in temporary housing communities. The system leverages aesthetic, technical functionality, and community input, enhancing sustainable water management practices. This study highlights that modular greywater planters designed from readily available materials can supply an effective, community-accepted approach to greywater recycling in temporary housing contexts. Greywater recycling and monitoring can culminate in improved environmental and social outcomes, enhance the quality of life of communities by minimizing costs, and provide a strong and safe water management strategy if greywater is properly handled and treated. Greywater recycling appears to be a sustainable and feasible option for the future, especially for regions encountering water scarcity, unhoused populations, and, in extreme cases, disaster management. Recycling greywater encourages less water extraction from streams and rivers, and a lower quantity of wastewater passing through sewer or septic systems. Greywater recycling can be useful for activities that do not demand or necessitate that the quality of water should be at optimum levels.

To summarize the situation

1) Current situation: The greywater planters are meant to evapo-transpirate greywater, the point is not treatment in this case. This is type 1 greywater reuse under the Oregon DEQ regulations, water flows untreated into the planters where the water needs to remain in the subsurface before the plants evapo-transpirate it.

2) Future Changes: However, CSS would now like to reuse greywater for community gardening projects, this would likely mean they would be needing type 2 greywater reuse which includes drip irrigation and soak away pit or landscape pond disposal. This would require chemical and/or biological treatment (biosand filter and chlorine).

3) Thus, they need to know what the current state of the microbial water quality is in order to appropriately address the intended reuse application.

4) The sampling done is not sufficient in scale to make statistically significant inferences; this study is a purely qualitative understanding of how water quality is impacted by the systems, and thus will allow for recommendations for an enhanced system with treatment.

5) The result of this sampling found that further treatment and disinfection processes or technologies will need to be added to the greywater planter system before type 2 greywater reuse will be feasible.

According to Kordana-Obuch et al. (2023), making good use of greywater is a big step towards both Sustainable Development Goal Six (Clean Water and Sanitation) and Sustainable Development Goal Seven (Affordable and Clean Energy). However, given climate change coupled with limited access to water and sanitation facilities, achieving SDG 6 in low-income communities would undoubtedly take longer than expected (Madzaramba & Zanamwe, 2023). Recycling greywater to supplement water supplies and enhance sanitation in low-income areas is one possible strategy to get beyond this obstacle (Vergine et al., 2017; Ibekwe et al., 2018; Ofori et al., 2021). Greywater recycling will be a potent alternative to addressing the urgent water deficits (Sudarsan & Renganathan, 2011).

Even though greywater contains hair, food particles, grease, and other forms of contamination, it can still be appropriate to use greywater, particularly for non-potable uses (Pachkor et al., 2017). Greywater recycling systems are full of promise in terms of high-water savings for urban areas that have very large populations and elevated levels of daily water consumption per capita (Leong et al., 2017). As Climate change has become more pronounced, water conservation has become extremely critical, and every single drop of water needs to be taken into consideration. Greywater is capable of being recycled with ease; nevertheless, it has been neglected historically (Halwani et al., 2018). It is safer for Greywater to be disinfected and treated before reuse. Greywater can be disinfected via various methods, such as Ultraviolet disinfection, ozone disinfection, or chlorine. The most recommended method is disinfection with chlorine, as it is widely available and more affordable compared to other methods (Oh et al., 2018).

Chlorination may be necessary from time to time to kill pathogens. A chlorination unit is also necessary to attain residual chlorine and total coliform standards. Routine water testing is needed to ensure that the systems are working as they should and not pose a significant threat to human and environmental health, of which vulnerable communities/ individuals may be hit the hardest. Greywater can be recycled without danger or harm if it undergoes simple treatments. Given the high volumes of greywater generated in schools, homes, and universities, greywater has great possibilities for reclamation and treatment (Siwila & Kapesa, 2022). Greywater is a water resource that could tackle sanitation issues in low-income areas and vulnerable communities while expanding access to water (Madzaramba & Zanamwe, 2023).

Recommendations

The luxury of one-time water usage should therefore no longer be necessary for society as long as water quality can be guaranteed and ethically sustained (Meneses et al., 2010). Water recycling should consistently rely on public approval, engineering viability, health protection, and the community's perception of the water's worth (Meneses et al., 2010).

Because of the elevated input of non-fecal coliforms and/or growth/flourishing of coliforms, greywater recycling guidelines/regulations should not focus or rely on thermotolerant coliforms as a hygienic criterion. However, the increased receptiveness to treatment and environmental die-off to some extent offsets the overestimation of the fecal burden and, therefore, associated risk (Ottoson & Stenström, 2003).

The time between irrigation and public access to the place where irrigation water is used should be lengthened (Ottoson & Stenström, 2003). Another system technique to minimize risks associated with bacterial pathogens and indicator organisms is to detach kitchen sink waste from the greywater. This will substantially aid in reducing the growth factors in the greywater systems (Ottoson & Stenström, 2003).

Future Work

Future work comprises an evaluation of planter impact on treatment efficacy, long-term treatment performance monitoring (longer testing periods). Additionally, the soils in the planters could be analyzed and tested for heavy metals such as mercury, lead, cadmium, etc.

Additional investigation to see if there will be any seasonal variation in the results. Does the system work better in certain seasons? This could be addressed with a longer testing period.

Qualitative Data Collection

Public perception thus obtaining robust feedback from the community/public on the system.

Filtration

One greywater treatment strategy that is gaining attention is the use of biochar. Biochar, which looks like charcoal, is a waste-based adsorbent material that is porous, has a reactive surface functional group, and extremely large surface area. These properties of biochar make it a good prospect as an adsorbent in wastewater treatment (Quispe et al., 2022). Future tests and system design implementation could include biochar.

Turbidity

Greywater turbidity ranges from 19 to 444 NTU, with water-use activities having the greatest impact on this range. It is anticipated and perceived that the presence of suspended matter will render greywater, primarily originating from sources such as laundry and the kitchen, have a much higher turbidity (Oteng-Peprah et al., 2018). The greywater planters now in use were designed to reduce turbidity not treat or eliminate bacterial contaminants (Oteng-Peprah et al., 2018). Testing the effectiveness of turbidity reduction of the system in the future would be a good next step.

EPA Water Quality Standards

While we were aiming to meet Oregon DEQ standards for greywater reuse, US EPA standards are much stricter. The strictest requirements include a turbidity of less than or equal to 2 NTU, a biochemical oxygen demand (BOD) below or equal to 10 mg/l, and an undetectable amount of either fecal or total coliforms per 100 ml (USEPA, 2012; Tajima et al., 2006). Other, less stringent standards, on the other hand, permit much more elevated concentrations of the distinct parameters or completely rule out some of these parameters (Gross et al., 2007). For instance, for water reuse for non-food crops (irrigation), the requirements are less than or equal to 200 fecal coliforms per 100 ml. Moreover, a PH of 6.0 - 9.0 (USEPA, 2012). Meeting the US EPA standards would allow larger adoption throughout the US.

To ensure that the effluent from a greywater treatment system satisfies the necessary effluent standards, designing greywater systems that target specific recycling options while factoring in certain geographical complexities and differences will be a wise approach (Oteng-Peprah et al., 2018).

Reuse Category and Description	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Urban Reuse					
Unrestricted The use of reclaimed water in nonpotable applications in municipal settings where public access is not restricted.	▪ Secondary (4) ▪ Filtration (5) ▪ Disinfection (6)	▪ pH = 6.0-9.0 ▪ ≤ 10 mg/l BOD (7) ▪ ≤ 2 NTU (8) ▪ No detectable fecal coliform /100 ml (9,10) ▪ 1 mg/l Cl2 residual (min.) (11)	▪ pH – weekly ▪ BOD - weekly ▪ Turbidity - continuous ▪ Fecal coliform - daily ▪ Cl2 residual – continuous	▪ 50 ft (15 m) to potable water supply wells; increased to 100 ft (30 m) when located in porous media (18)	▪ At controlled-access irrigation sites where design and operational measures significantly reduce the potential of public contact with reclaimed water, a lower level of treatment, e.g., secondary treatment and disinfection to achieve < 14 fecal coli/100 ml may be appropriate. ▪ Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. ▪ The reclaimed water should not contain measurable levels of pathogens. (12) ▪ Reclaimed water should be clear and odorless. ▪ Higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. ▪ Chlorine residual > 0.5 mg/l in the distribution system is recommended to reduce odors, slime, and bacterial regrowth. ▪ See Section 3.4.3 in the 2004 guidelines for recommended treatment reliability requirements.
Restricted The use of reclaimed water in nonpotable applications in municipal settings where public access is controlled or restricted by physical or institutional barriers, such as fencing, advisory signage, or temporal access restriction	▪ Secondary (4) ▪ Disinfection (6)	▪ pH = 6.0-9.0 ▪ ≤ 30 mg/l BOD (7) ▪ ≤ 30 mg/l TSS ▪ ≤ 200 fecal coliform /100 ml (9, 13, 14) ▪ 1 mg/l Cl2 residual (min.) (11)	▪ pH – weekly ▪ BOD – weekly ▪ TSS – daily ▪ Fecal coliform - daily ▪ Cl2 residual – continuous	▪ 300 ft (90 m) to potable water supply wells ▪ 100 ft (30 m) to areas accessible to the public (if spray irrigation)	▪ If spray irrigation, TSS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. ▪ See Section 3.4.3 in the 2004 guidelines for recommended treatment reliability requirements. ▪ For use in construction activities including soil compaction, dust control, washing aggregate, making concrete, worker contact with reclaimed water should be minimized and a higher level of disinfection (e.g. < 14 fecal coli/100 ml) should be provided when frequent worker contact with reclaimed water is likely.
Agricultural Reuse					
Food Crops [15] The use of reclaimed water for surface or spray irrigation of food crops which are intended for human consumption, consumed raw.	▪ Secondary (4) ▪ Filtration (5) ▪ Disinfection (6)	▪ pH = 6.0-9.0 ▪ ≤ 10 mg/l BOD (7) ▪ ≤ 2 NTU (8) ▪ No detectable fecal coliform/100 ml (9,10) ▪ 1 mg/l Cl_2 residual (min.) (11)	▪ pH – weekly ▪ BOD - weekly ▪ Turbidity - continuous ▪ Fecal coliform - daily ▪ Cl_2 residual – continuous	▪ 50 ft (15 m) to potable water supply wells; increased to 100 ft (30 m) when located in porous media (18)	▪ See Table 3-5 for other recommended chemical constituent limits for irrigation. ▪ Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. ▪ The reclaimed water should not contain measurable levels of pathogens. (12) ▪ Higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. ▪ High nutrient levels may adversely affect some crops during certain growth stages. ▪ See Section 3.4.3 in the 2004 guidelines for recommended treatment reliability requirements.
Processed Food Crops [15] The use of reclaimed water for surface irrigation of food crops which are intended for human consumption, commercially processed. ***Non-Food Crops*** The use of reclaimed water for irrigation of crops which are not consumed by humans, including fodder, fiber, and seed crops, or to irrigate pasture land, commercial nurseries, and sod farms.	▪ Secondary (4) ▪ Disinfection (6)	▪ pH = 6.0-9.0 ▪ ≤ 30 mg/l BOD (7) ▪ ≤ 30 mg/l TSS ▪ ≤ 200 fecal coli/100 ml (9,13, 14) ▪ 1 mg/l Cl2 residual (min.) (11)	▪ pH – weekly ▪ BOD - weekly ▪ TSS - daily ▪ Fecal coliform - daily ▪ Cl_2 residual – continuous	▪ 300 ft (90 m) to potable water supply wells ▪ 100 ft (30 m) to areas accessible to the public (if spray irrigation)	▪ See Table 3-5 for other recommended chemical constituent limits for irrigation. ▪ If spray irrigation, TSS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. ▪ High nutrient levels may adversely affect some crops during certain growth stages. ▪ See Section 3.4.3 in the 2004 guidelines for recommended treatment reliability requirements. ▪ Milking animals should be prohibited from grazing for 15 days after irrigation ceases. A higher level of disinfection, e.g., to achieve < 14 fecal coli/100 ml, should be provided if this waiting period is not adhered to.

Figure 11: EPA water reuse guidelines. Source: EPA water reuse guidelines 2012

REFERENCES

Ajit, K. (2016). A review of grey water treatment and reuse. International Research Journal of Engineering and Technology, 3(5), 2665-2668.

Alig, S. (2021). *Carving a new path4 forward: Advocating for transitional housing to help mitigate oppressive forces for people disproportionately affected by homelessness* [Master's thesis, University of Oregon]. Scholars' Bank. https://scholarsbank.uoregon.edu/items/0c8ced1e-5305-4324-a7e7-95bde7020422

Allen, L., Christian-Smith, J., Palaniappan, M., & Pacific Institute. (2010). *Overview of Greywater reuse: The potential of greywater systems to aid sustainable water management*. Pacific Institute. https://pacinst.org/wp-content/uploads/sites/21/2013/02/greywater_overview1.pdf

Angelakis, A. N., Asano, T., Bahri, A., Jimenez, B. L., & Tchobanoglous, G. (2018). Water reuse: From ancient to modern times and the future. *Frontiers in Environmental Science, 6*, 26.https://doi.org/10.3389/fenvs.2018.00026

Armah, F. A., Ekumah, B., Yawson, D. O., Odoi, J. O., Afitiri, A. R., & Nyieku, F. E. (2018). Access to improved water and sanitation in sub-Saharan Africa in a quarter century. *Heliyon, 4*(11), e00931.https://doi.org/10.1016/j.heliyon.2018.e00931

Bisung, E., & Dickin, S. (2019). Concept mapping: Engaging stakeholders to identify factors that contribute to empowerment in the water and sanitation sector in West Africa. *SSM - Population Health*, *9*, 100490. https://doi.org/10.1016/j.ssmph.2019.100490

Bolton, C. R., & Randall, D. G. (2019). Development of an integrated wetland microbial fuel cell and sand filtration system for greywater treatment. Journal of Environmental Chemical Engineering, 7(4), 103249. https://doi.org/10.1016/j.jece.2019.103249

Bonkoski, S. (2023). Homeless Policy in Eugene, Oregon: A critical examination of the West Coast from a Social Construction Framework. Oregon State University.

Boufaroua, M., Albalawneh, A., & Oweis, T. (2013). Assessing the efficiency of grey-water reuse at the household level and its suitability for sustainable rural and human development. British Journal of Applied Science & Technology, 3(4), 962.

Brodka, B., Cansdale, M., Driggs, M., Lawrenz, O., Padawer, R., Soria, L., & Stout, L. (n.d.). *Greywater Planter Manual: For LA 410/510 – Design for Climate Action*. University of Oregon. Retrieved from https://www.koryrussel.com/_files/ugd/cd823e_3c0391268d624245983487c39bbbcdf8.pdf

Coats, E. R., & Wilson, P. I. (2017). Toward nucleating the concept of the water resource recovery facility (WRRF): perspective from the principal actors. Environmental Science & Technology, 51(8), 4158-4164.

Community Supported Shelters. (n.d.). *Helping the unhoused rebuild their lives*. https://www.communitysupportedshelters.org/

De Gisi, S., Casella, P., Notarnicola, M., & Farina, R. (2016). Grey water in buildings: a mini-review of guidelines, technologies and case studies. Civil Engineering and Environmental Systems, 33(1), 35-54.

DeOreo, W. B., Mayer, P. W., Dziegielewski, B., & Kiefer, J. C. (2016). *Residential end uses of water, version 2*. Water Research Foundation. https://www.waterrf.org/research/projects/residential-end-uses-water-version-2

Edwin, G. A., Gopalsamy, P., & Muthu, N. (2014). Characterization of domestic gray water from point source to determine the potential for urban residential reuse: A short review. *Applied Water Science, 4,* 39–49. https://doi. org/10.1007/s13201-013-0128-8.

Elhegazy, H., & Eid, M. M. (2020). A state-of-the-art-review on grey water management: a survey from 2000 to 2020s. Water Science and Technology, 82(12), 2786-2797.

Friedler, E. (2004). Quality of Individual Domestic Greywater Streams and its Implication for On-Site Treatment and Reuse Possibilities. *Environmental Technology*, *25*(9), 997–1008. https://doi.org/10.1080/09593330.2004.9619393

Garcia-Cuerva, L., Berglund, E. Z., & Binder, A. R. (2016). Public perceptions of water shortages, conservation behaviors, and support for water reuse in the US. Resources, Conservation and Recycling, 113, 106-115.

Garrick, D., Iseman, T., Gilson, G., Brozovic, N., O'Donnell, E., Matthews, N., ... & Young, W. (2020). Scalable solutions to freshwater scarcity: Advancing theories of change to incentivise sustainable water use. *Water Security*, *9*, 100055.

Gross, A., Shmueli, O., Ronen, Z., & Raveh, E. (2007). Recycled vertical flow constructed wetland (RVFCW) – a novel method of recycling greywater for irrigation in small communities and households. *Chemosphere, 66(5),* 916–923.

Halwani, B., Net, S., Ouddane, B., & Halwani, J. (2018). A review of the most popular systems for greywater treatment. Desalination and Water Treatment, 135, 124-132.

Ibekwe, A. M., Gonzalez-Rubio, A., & Suarez, D. L. (2018). Impact of treated wastewater for irrigation on soil microbial communities. *Science of the Total Environment, 622–623*, 1603–1610.https://doi.org/10.1016/j.scitotenv.2017.10.039

James, D. T. K., Surendran, S., Ifelebuegu, A. O., Ganjian, E., & Kinuthia, J. (2016, December). Grey water reclamation for urban non-potable reuse–challenges and solutions: a review. In Proceeding 7th International Conference on Sustainable Built Environment At: Sri Lanka (Kandy).

Kobayashi, Y., Ashbolt, N. J., Davies, E. G., & Liu, Y. (2020). Life cycle assessment of decentralized greywater treatment systems with reuse at different scales in cold regions. *Environment international*, *134*, 105215.https://doi.org/10.1016/j.envint.2019.105215

Kordana-Obuch, S., Starzec, M., Wojtoń, M., & Słyś, D. (2023). Greywater as a future sustainable energy and water source: Bibliometric mapping of current knowledge and strategies. Energies, 16(2), 934.

Lane County Human Services Division. (2025, May 29). *Lane County's 2025 Point-in-Time count shows increase in homelessness*. Lane County Government. https://www.lanecountyor.gov/news/archived_news/PR_HHS_052925_PITCountData

Larsen, T. A., Hoffmann, S., Lüthi, C., Truffer, B., & Maurer, M. (2016). Emerging solutions to the water challenges of an urbanizing world. *Science*, *352*(6288), 928-933.

Leong, J. Y. C., Oh, K. S., Poh, P. E., & Chong, M. N. (2017). Prospects of hybrid rainwater-greywater decentralised system for water recycling and reuse: A review. Journal of Cleaner Production, 142, 3014 3027. https://doi.org/10.1016/j.jclepro.2016.10.167

Levine, A. D., & Asano, T. (2004). Recovering sustainable water from wastewater. *Environmental Science & Technology, 38(11)*, 201A–208A

Li, F., Wichmann, K., & Otterpohl, R. (2009). Review of the technological approaches for grey water treatment and reuses. *Science of the Total Environment, 407*, 3439–3449. https://doi.org/10.1016/j.scitotenv.2009.02.004.

Madzaramba, T. H., & Zanamwe, P. (2023). User perceptions and acceptance of treated greywater reuse in low-income communities: a narrative review. *Journal of Water and Climate Change*, *14*(11), 4236–4244. https://doi.org/10.2166/wcc.2023.414

Maimon, A., Tal, A., Friedler, E., & Gross, A. (2010). Safe on-site reuse of greywater for irrigation-a critical review of current guidelines. Environmental science & technology, 44(9), 3213-3220.

Maimon,A.,Friedler, E., & Gross,A.(2014).Parametersaffecting greywater quality and its safety for reuse. *Science of the Total Environment, 487*, 20–25. https://doi.org/10.1016/j. Scitotenv.2014.03.133.

Maraqa, M. A., & Ghoudi, K. (2016). Public perception of water conservation, reclamation and greywater use in the United Arab Emirates. International Proceedings of Chemical, Biological and Environmental Engineering, 91, 24-30.

Meneses, M., Pasqualino, J. C., & Castells, F. (2010). Environmental assessment of urban wastewater reuse: Treatment alternatives and applications. *Chemosphere*, *81*(2), 266–272. https://doi.org/10.1016/j.chemosphere.2010.05.053

NOAA National Centers for Environmental Information (NCEI). (2025). *U.S. Billion-Dollar Weather and Climate Disasters*. https://www.ncei.noaa.gov/access/billions/ https://www.doi.org/10.25921/stkw-7w73

O'Toole, J., Sinclair, M., Malawaraarachchi, M., Hamilton, A., Barker, S. F., & Leder, K. (2012). Microbial quality assess ment of household greywater. *Water Research, 46,* 4301 4313. https://doi.org/10.1016/j.watres.2012.05.001.

Ofori, S., Puškáčová, A., Růžičková, I., & Wanner, J. (2021). Wastewater reuse for irrigation: Pros and cons. *Science of the Total Environment, 760*, 144026. https://doi.org/10.1016/j.scitotenv.2020.144026

Oh, K. S., Leong, J. Y. C., Poh, P. E., Chong, M. N., & Lau, E. V. (2018). A review of greywater recycling related issues: Challenges and future prospects in Malaysia. Journal of Cleaner Production, 171, 17-29. https://doi.org/10.1016/j.jclepro.2017.09.267

Oregon Department of Environmental Quality. (n.d.). *Rules on graywater reuse and disposal systems*. https://www.oregon.gov/deq/filterpermitsdocs/graywaterrules.pdf

Oteng-Peprah, M., Acheampong, M. A., & deVries, N. K. (2018). Greywater Characteristics, treatment systems, reuse strategies and user perception—a review. *Water Air & Soil Pollution*, *229*(8), 255. https://doi.org/10.1007/s11270-018-3909-8

Ottoson, J., & Stenström, T. A. (2003). Faecal contamination of greywater and associated microbial risks. *Water Research*, *37*(3), 645–655. https://doi.org/10.1016/s0043-1354(02)00352-4

Pachkor, R. T., & Parbat, D. K. (2017). A Literature Review on Integrated Approach for Grey Water Treatment. International Journal for Research in Applied Science & Engineering Technology.

Paleologos, E. K., Elhakeem, M., El Amrousi, M., Canal-Forgues, E., & Saba, M. (2019). Greywater reuse in the water-scarce Gulf Region. *IOP Conference Series: Earth and Environmental Science, 344*(1), 012005. https://doi.org/10.1088/1755-1315/344/1/012005

Pidou, M., Avery, L., Stephenson, T., Jeffrey, P., Parsons, S. A., Liu, S., Memon, F. A., & Jefferson, B. (2008). Chemical solutions for greywater recycling. *Chemosphere*, *71*(1), 147–155. https://doi.org/10.1016/j.chemosphere.2007.10.046

Pradhan, S., Pradhan, B., & Joshi, A. (2025). Leveraging geographic information systems (GIS) in water, sanitation, and hygiene (WASH) research: A systematic review of applications and challenges. *Spatial Information Research*, *33*(2). https://doi.org/10.1007/s41324-025-00613-4

Quispe, J. B., Campos, L. C., Mašek, O., & Bogush, A. (2022). Use of biochar-based column filtration systems for greywater treatment: A systematic literature review. Journal of Water Process Engineering, 48, 102908.

Sachs, J.D., Lafortune, G., Fuller, G., Iablonovski, G. (2025). *Financing Sustainable Development to 2030 and Mid-Century*. Sustainable Development Report 2025. Paris: SDSN, Dublin: Dublin University Press. DOI: https://doi.org/10.25546/111909

San Francisco Public Utilities Commission. (2017). *San Francisco graywater design manual for outdoor irrigation*. https://www.sfpuc.gov/sites/default/files/documents/Graywater_Design_Manual.pdf

Siwila, S., & Kapesa, E. (2022). Treatment of domestic greywater using fly ash as an adsorbent incorporated in a slow sand filtration system. Water Practice & Technology, 17(5), 961-973.

Smol, D. M. (2023). Special issue on the 3rd International Conference Strategies toward Green Deal Implementation-Water and Raw Materials (ICGreenDeal2021) 5–7 December 2022, Cracow, Poland online. DESALINATION AND WATER TREATMENT, 295, 1-1.

Solari, C. D., Dr., Morris, S., Shivji, A., De Souza, T., Abt Associates, Bishop, K., Savidge-Wilkins, G., Ballinger, S., Barker, K., Bradshaw, J., Brann, J., Cummings, K., delaCruz, R., Eltahir, N., Engle, H., Epstein, Z., Hall, A., Hillard, M., Huq, M., . . . Dupree, D. (2016). The 2015 Annual Homeless Assessment Report (AHAR) to Congress. In J. Khadduri Dr., Abt Associates, & D. Culhane Dr., *The U.S. Department of Housing and Urban Development*.

Sudarsan, J. S., & Renganathan, K. (2011). A GIS approach for decentralised grey water treatment. *Journal of Environmental Research and Development, 5*(4), 1004–1005.

Taher, M. N., Awayes, J., Cavkas, S., & Beler-Baykal, B. (2019). Public attitude for acceptance of grey water reuse in Istanbul and the impact of informing potential consumers. Desalination and Water Treatment, 172, 316-322.

Tajima, A., Sakurai, K., & Minamiyama, M. (2006). Behavior of pathogenic microbes in a treated wastewater reuse system and examination of new standards for the reuse of treated wastewater. *Environmental Monitoring and Assessment*, *129*(1–3), 43–51. https://doi.org/10.1007/s10661-006-9424-1

Travis, M. J., Weisbrod, N., & Gross, A. (2008). Accumulation of oil and grease in soils irrigated with greywater and their potential role in soil water repellency. *The Science of the Total Environment*, *394*(1), 68–74. https://doi.org/10.1016/j.scitotenv.2008.01.004

U.S. Environmental Protection Agency. (2012). *Guidelines for water reuse* (EPA/600/R-12/618). U.S. Environmental Protection Agency,Washington, DC, USA.

U.S. Environmental Protection Agency. (2025, March 6). *Residential toilets*. EPA WaterSense. Retrieved from https://www.epa.gov/watersense/residential-toilets

United Nations. (2014). *The road to dignity by 2030: Ending poverty, transforming all lives and protecting the planet. Synthesis report of the Secretary-General on the post-2015agenda.* In *United Nations* (A/69/700; pp. 1–34).

United Nations. (2016). T*he Sustainable Development Goals Report 2016.* http://unstats.un.org/sdgs/report/2016/

United Nations. (2025). *The Sustainable Development Goals report 2025.* United Nations. https://unstats.un.org/sdgs/report/2025/The-Sustainable-Development-Goals-Report-2025.pdf

Van de Walle, A., Kim, M., Alam, M. K., Wang, X., Wu, D., Dash, S. R., ... & Kim, J. (2023). Greywater reuse as a key enabler for improving urban wastewater management. *Environmental science and ecotechnology*, 100277.

Vergine, P., Salerno, C., Libutti, A., Beneduce, L., Gatta, G., Berardi, G., & Pollice, A. (2017). Closing the water cycle in the agro-industrial sector by reusing treated wastewater for irrigation. *Journal of Cleaner Production, 164*, 587–596. https://doi.org/10.1016/j.jclepro.2017.06.239

Vuppaladadiyam, A. K., Merayo, N., Prinsen, P., Luque, R., Blanco, A., & Zhao, M. (2019). A review on greywater reuse: quality, risks, barriers and global scenarios. Reviews in Environmental Science and Bio/Technology, 18, 77-99.

Wallin, J., Knutsson, J., & Karpouzoglou, T. (2021). A multi-criteria analysis of building level graywater reuse for personal hygiene. Resources, Conservation & Recycling Advances, 12, 200054.

WHO & UNICEF. (2021). *Joint Monitoring Program for Water Supply, Sanitation and Hygiene (JMP) – Progress on household drinking water, sanitation and hygiene 2000–2020*. World Health Organization. https://www.who.int/water_sanitation_health/publications/jmp-2021-report

Wolf, J., Hubbard, S., Brauer, M., Ambelu, A., Arnold, B. F., Bain, R., Bauza, V., Brown, J., Caruso, B. A., Clasen, T., Colford, J. M., Freeman, M. C., Gordon, B., Johnston, R. B., Mertens, A., Prüss-Ustün, A., Ross, I., Stanaway, J., Zhao, J. T., . . . Boisson, S. (2022). Effectiveness of interventions to improve drinking water, sanitation, and handwashing with soap on risk of diarrhoeal disease in children in low-income and middle-income settings: A systematic review and meta-analysis. *The Lancet*, *400*(10345), 48–59. https://doi.org/10.1016/s0140-6736(22)00937-0

World Health Organization. (2023). *Burden of disease attributable to unsafe drinking-water, sanitation and hygiene: 2019 update.* World Health Organization. *https://www.who.int/publications/i/item/9789240075610*

World Meteorological Organization (WMO). (2021). *2021 state of climate services: Water-Climate risk & early warning systems* (M. Dilley, V. F. Grasso, & N. Msemo, Eds.). World Meteorological Organization. https://library.wmo.int/viewer/57630/download?file=1278_en.pdf&type=pdf&navigator=1